Holmgren (F.)

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RELATION TO ACCIDENTS BY RAIL AND SEA.

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PROF. F. HOLMGREN,
OF THE UNIVERSITY OF UPSAL, SWEDEN.

FROM THE REPORT OF THE SMITHSONIAN INSTITUTION FOR 1877.

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By F. Holmgren,
Professor of Physiology at the University of Upsal.
[Translated for the Smithsonian Institution by M. L. Duncan.]*

INTRODUCTION.

In several preceding memoirs I have treated the subject of color-blindness from the theoretical side of this singular phenomenon. But it has, likewise, a practical side of vast importance; for not only does this defect of vision every day give rise to inconveniences in the various departments of the sciences, arts, and industries, but it is also the cause of most disastrous accidents by rail and by sea. Public attention has been attracted to this side of the question by scientific works or by accidents, and to judge from certain facts reported in books and newspapers, there now seems to prevail a more general conviction of the necessity of making the sense of color amongst seamen and railway employés an object of official scrutiny and control in order to guard against this hidden danger, to which too little attention has been given. Our times are probably ripe for such a reform, and there is only wanting, it seems, for its immediate and general adoption, a practical method, a well-arranged plan, and initiatory energy. It is to supply these deficiencies that we have undertaken and published these pages.

To Sweden belongs the honor of having taken the initiative in this reform, and in such a manner as to exercise a full control over the sense of color on all our railways. This reform was promptly matured, and introduced in a not less rapid, sure, and systematic manner, which undoubtedly proves the advantages of the method, plan, and principles which were followed.

A knowledge of the method of investigation and of the principles relating to it has been so far disseminated merely by oral exposition and application before the physicians and railway employés in the Amphitheatre of Physiology of Upsal, during the latter part of the year 1876. Consequently, what is remarkable with regard to the subject is that the entire reform was established in Sweden before any rules or principles were printed. One of the most important causes of this fact is found in the conviction felt from the first of the advantages of speech over writing in such matters. The other reason is that our results were obtained with unexpected rapidity, and that the time devoted to it pre-

* This article has been necessarily somewhat abridged from the French translation: De la Cécité des Couleurs, dans ses rapports avec les Chemins-de-fer et la Marine, par F. Holmgren. Traduit du suédors avec l'autorisation de l'auteur. Stockholm. 8 vo. pp. 144. [1877.]

vented us from publishing this work before the reform was introduced. If this fact should render the publication of these labors less indispensable for the time being, we must not forget the importance and necessity of directions which will serve in the future for our own railways, as well as for the introduction of a similar reform elsewhere.

The importance of uniformity in the method of examination, in the classification, and in the principles relating to the disposal of the *personnel*, cannot be too highly estimated, for this is of consequence, not only to science, and especially to statistics, but also to a purely practical end. This fact becomes the more forcible when connected with the investigation of the sense of color among seamen; for every reform of this kind within the province of navigation naturally assumes an international character. Our classification as well as our method of examining the color-blind is founded upon the Young-Helmholtz theory, and we cannot refrain from enumerating here the principal elements. This theory is assuredly not the only one, nor even the last that has been given to the public and gained partisans; but it is, in our opinion, the best for the end in view, and it will be seen that it essentially responds, as far as regards practical interest, to all that we have a right to require of a theory. We have no intention of attempting to establish its correctness. We make use of it for a definite purpose, under the conviction that it is a needful basis for the systematic and accurate solution of some of the practical questions under consideration.

In brief, the object of this work is to give a practical and clear idea of the nature of color-blindness, of its importance to marine and railway service, and, finally, a concise summary of the principles to be followed and the measures to be taken in order to secure immunity from its peculiar dangers. The reason why we confine ourselves almost exclusively to railways here is that the reform in view has already been introduced into this department, and a valuable experience acquired. And it is clear that these results may equally well be applied to navigation, at least in all essentials.

Color-blindness in many other departments of practical life also leads to serious inconveniences, and as it is desirable that an examination of the chromatic sense be undertaken on a large scale in schools, as a guide in the choice of professions, we hope this memoir may serve in a measure to this end. We should, moreover, be very happy to have the opportunity (so rarely accorded to physiology) of being useful to humanity, without the intervention of practical medicine.

I.—HISTORICAL SKETCH.

Color-blindness has been known for a long time, and, therefore, has its history. The first cases known to the public are mentioned in a letter from Joseph Huddart* to Joseph Priestley, dated January 15, 1777,

* An Account of persons who could not distinguish colors. By Mr. Joseph Huddart, in a letter to the Rev. Joseph Priestley, L.L.D., F.R.S. Philosophical Transactions of the Royal Society of London. Vol. lxvii. For the year 1777, part i, p. 260.

just one hundred years ago. The cases in point were those of a shoemaker, named Harris, of Mary-port, in Cumberland, and his brother, master of a merchant-vessel, belonging to the same port. Although the description is very brief, several features, which at a later date characterized complete color-blindness, are recognized, and especially in the latter case the type of blindness known at present under the name of *red-blindness*.

The first case of color-blindness accurately described, known to us, is that of John Dalton, the celebrated English chemist and physicist. Unable to distinguish red, he studied this defect of nature in himself, and published in 1794 a detailed and accurate description of it.* It is after him that color-blindness received the name of *Daltonism*, an appellation which appears to have been employed for the first time by Pierre Prévost, at Geneva, in 1827, and was, therefore, in use during the life of Dalton, who did not die until 1844. It is not known whether Dalton was aware of this appellation, but, however that may be, he probably would not have objected to this use of his name, for according to George Wilson he was more amused than annoyed by his defect, he himself enjoying the amusement he afforded others by his mistakes in colors. His countrymen have, however, warmly protested against this manner of immortalizing the memory of Dalton by perpetuating a congenital defect, especially as his scientific merits are sufficient to render his name imperishable. But notwithstanding these protestations, and the universal use in England of the name of *color-blindness*, which was first introduced by Sir David Brewster, and is now in general use in Germany (*farbeblindheit*), the terms *Daltonisme* and *Daltonien* are still in common use in France.

Dalton also cites a number of instances of color-blindness, similar to his own, and later a host of others are mentioned by different authors; but, on the whole, these are isolated cases accidentally encountered, and considered as curiosities, and their most striking features described and discussed, but with no knowledge of how to reduce them to fixed laws. For this purpose, three things were especially wanting: a practical method of investigation, a large material for the purpose, and a satisfactory theory for direction in the employment of this material.

Seebeck was the first to interest himself especially in systematically collecting a number of cases relatively very large, and in comparing them with each other. In 1837 he made a strict examination of the students of one class in a school in Berlin, and gave a detailed account of twelve cases of complete color-blindness examined by himself, and of one mentioned by his father, as well as a few other instances more or less color-blind, which form the transition between complete color-blindness and the normal chromatic sense. Seebeck understood the uncer-

* Extraordinary facts relating to the vision of colors: with observations by Mr. John Dalton, read October 31st, 1794. Memoirs of the Literary and Philosophical Society of Manchester. Vol. v, part i (1798), p. 28.

tainty and inadmissibility of attempting to discover the nature of this blindness by simply interrogating the color-blind as to the names of the colored objects; he was careful to note what mistakes they made in comparing the colors, or, in other words, he ascertained between what colors, different to the normal eye, they found resemblances. Following up this principle, he proceeded methodically to examine individuals; he invited them to arrange, in the order of their resemblances to each other, a number of colored objects, which in the beginning were in confusion. He used principally paper, about three hundred pieces of different colors, not, however, rejecting other materials, especially pieces of colored glass. He objected to silk on account of its brilliancy, but recommended wool, although he does not appear himself to have preferred to use it. It is not clear from Seebeck's writings whether, after each examination, he preserved the order in which these pieces of paper were arranged by the color-blind; but it is certain he compared the manner of arranging them in different cases, and drew his own conclusions. By this comparison, Seebeck succeeded in pointing out two classes of specifically distinct color-blindness. Of the thirteen cases he examined, eight belonged to the first and five to the second class. Moreover, he shows that in the two classes there is a great variety of degrees of color-blindness, and seeks further to prove the probable existence in the two classes of a gradual transition to the normal sense of color.

But Seebeck and his contemporaries, like their predecessors, could not discover a satisfactory explanation of the defect in question, or practically see its relation to the normal sense of color. This is easily explained by the fact that at this time there was not the least plausible system of a physiological doctrine of colors. Indeed, as early as the beginning of our century, a useful and satisfactory theory had been devised by Thomas Young, but it had been neglected or forgotten, as were many of the other ideas of this extraordinary man, who was far in advance of his age, and consequently not understood. The theory of the three primitive colors, or fundamental perceptions, of Young, was rescued from oblivion by Helmholtz about the year 1850, and also later, but independently, by Maxwell. This theory has undoubtedly already exerted a very happy influence over the physiological doctrine of colors in general, as well as over that of the anomaly in chromatic perception. In designating this theory by the names of both scientists, we thereby simply render justice to the merit which accrues to Helmholtz for having revived and applied it. Owing to this theory, the question of the nature of color-blindness has been of late the object of strong and growing interest. The number of cases, and also of treatises on the subject, have increased very considerably, and the study, undertaken by physiologists as well as by ophthalmological practitioners, has not been confined to congenital color-blindness and its different forms, but has also extended with much earnestness over pathological diagnostics. It is only about ten years since that a new theory, that of four cardinal colors, succeeded in making

many partisans. But when will it be in a condition to meet the exigencies of the physiological doctrine of colors in a more satisfactory manner than the Young-Helmholtz theory? This is yet unknown. With regard to the defect now occupying our attention, it seems very doubtful, to judge by the trials that have been made, whether this theory would better meet practical necessities than that of the three cardinal colors. And it is precisely these practical requirements that have led us to mention the theory here.

Up to the present time, the theoretical problem of color-blindness has undoubtedly been the object of more serious attention, and has been richer in results than the practical. Now, as the latter is nevertheless of singular importance, and the difficulties to be encountered to solve it in a satisfactory manner seem, in many respects, of only secondary importance, it is not easy, in reality, at the first approach, to find a suitable explanation. It will not, therefore, be uninteresting, we believe, to cast a rapid glance over this side of the question from a historical point of view, which will, in the first place, bring out the fact of which we speak, and perhaps also contribute to bring to light the point at which it is necessary to look for the cause of this state of things. The first writer who seriously occupied himself with the investigation of color-blindness in the various departments of practical life, and especially drew attention to the possible accidents occasioned by the employment of color-blind individuals on railways and at sea, and generally in all operations where colored signals are used, was George Wilson, professor of technology at the University of Edinburgh.* Wilson's researches were purely practical in aim and end. The mistakes made by the students of his laboratory in judging the colors of chemical precipitates led him to reflect upon this subject, after reading the memoir in which Dalton describes his own anomaly. For a long time, he tells us he scarcely dared suspect any of his pupils of having so rare an infirmity, but, like many after him, he took courage, proceeded to make an examination, and found that not only were his suspicions perfectly correct, but that color-blindness was far from being so uncommon as usually supposed.

He dilates at length, in his memoir, on the peculiar characteristics of seventeen color-blind individuals; eight were examined by himself, and the others described by different observers, or the color-blind themselves. These cases were distributed as follows: fourteen men and three women; sixteen cases were congenital, and one proceeded from a cerebral affection caused by a fall from a horse. It must be remembered that this last case had not been examined before the accident; a circumstance rendering the verification of the pathological origin of color-blindness difficult, but the description seems to authorize

* Researches on color-blindness, with a supplement on the danger attending the present system of railway and marine colored signals. By George Wilson. Edinburgh, 1855.

the conclusion that the case was correctly judged. Besides these cases described in detail, and illustrated by a number of interesting anecdotes, Wilson cites a great many others analogous, but only accidentally encountered by our author, or mentioned to him by other persons, for which he was indebted to the interest the question had excited in England by his own initiatory steps. Wilson's data are not merely limited to this kind of investigation. He also mentions the systematic researches, (analogous in some measure to those of Seebeck,) which he undertook in order to discover color-blind individuals, and by that means form some idea of the frequency of color-blindness amongst the population. It is to him, in fact, we owe the first efforts to establish regular statistics on this subject, as it would be difficult to receive as such the cases collected by Dalton. To attain this end, Wilson examined at the same time a large number of individuals belonging to the same class, such as soldiers, students, police-agents, veterinary students, etc., and discovered in this way 65 color-blind out of 1,154 persons examined; that is, 5.6 per cent., or one color-blind out of every 17.7 persons. If desired that statistics of this nature should render the service expected, it is plain that there must be great strictness in the use of the methods of examination, and especially in any case where a doubt of color-blindness exists. Here, as in the classification of color-blindness in general, theory exercises great influence. In this respect, it is very important that uniformity should prevail, or at least that, at the time of the employment of the different theories and methods, the limits should be well defined between color-blindness on one hand, and, on the other, between the different kinds of anomalies, and finally that the process should be so selected for examination and classification that from any practical point of view an accurate judgment could be formed of the result, and a classification made of the different cases under any system whatsoever. It is only by fulfilling these conditions that these statistical data can be useful; and that they may have a real value, it is the more necessary that the method should be so sure that no color-blind individual could escape the experimenter.

It is impossible to say that Wilson's statistics fulfill these requirements. Wilson was not ignorant of Young's theory as restored by Helmholtz and Maxwell. But this theory had not as yet begun to excercise a general influence over the ideas of the nature of the anomalous perception of colors, the methods employed in discovering it, and the manner of classifying the different forms. Wilson's method and classification therefore are deficient. His method consists in presenting to the individuals to be examined pieces of colored paper, one after the other, or a diagram in an illustrated work, and asking the names of the colors. Those only who evince some hesitation in distinguishing red, green, and brown are required to submit to Seebeck's proof, that is to say, classifying according to their analogy, but without indicating by name the pieces of colored paper, glass, or wool. From this it can be

quite positively concluded that this method is not altogether safe. Wilson acknowledges as possible that some of the color-blind might pass unperceived, especially when, to save time, the examination is made more hastily than the method allows.

The classification is not better regulated; in fact, it distributes the color-blind into three classes: 1st, those who confound red with green; 2d, those who confound brown with green; and, 3d, those who confound blue with green. This distribution is not founded upon any theory, nor is it either the exact expression of well-defined kinds. Wilson himself agrees that those who make the mistakes characterizing the first class do not fail to make those of the second also. The second group might therefore be correctly regarded as the same kind as the first, of an inferior degree. With regard to the third class, it is more than doubtful whether the greater number of the cases which it includes can be classed under the head of color-blindness. It also seems that Wilson hesitated with regard to this, since he has excluded this group from one of his tables. This class contributes the most also in rendering the proportion of color-blindness as great as Wilson found it. From these statements, the statistics given by this author cannot be regarded as very useful. Besides, the number of cases examined is too limited, especially as the particular figures forming the sum-total differ considerably among themselves. There is, however, another reason rendering Wilson's work of great importance, and worthy of being especially mentioned here. Wilson's constant aim, in fact, was to direct attention to color-blindness in its connection with practical life, and that in a very extended sense. He shows that an individual whose anomaly from infancy has been established should avoid selecting a profession in which his defective sense of color might occasion difficulties and annoyances to himself as well as to others. According to Wilson, the color-blind should never become painters, dyers, weavers, tailors, chemists, botanists, geologists, physicians, etc. Amongst the occupations in which the color-blind risk being the cause of embarrassments and annoyances to themselves as well as to others, and of real and serious accidents, Wilson especially mentions those of the sailor and railway employé, because the color-blind, who have a peculiar tendency to confound the very colors employed as signals at sea and on railways, may in this way occasion even death itself.

Wilson does not confine himself to pointing out these dangers to their full extent, but proposes preventive measures. For this purpose, he suggests very sensibly the only two measures that could be taken: to preserve the colored signals in actual use,—red (= danger), green (= attention), and white (the ordinary light of lanterns, that is yellow = clear track), and in this case eliminate all the color-blind; or else retain all, and change the signals. Wilson decides in favor of the latter alternative, which he considers preferable. He says that the managers of railways have been very unfortunate in their choice of colors, selecting precisely those, red and green, the color-blind confound the most.

This opinion does not extend to the signals used during the day. But Wilson fails, and very naturally, when he proposes other colors preferable, according to his judgment, for night-signals; for example, a blue light, excellent in all other respects, cannot fail to be useless in consequence of the small amount of power it is capable of acquiring in an ordinary lantern. Wilson reaches the conclusion that colors should be discarded as principal signals; they should be employed, he says, only as auxiliary, and founds his system of signals on *form*, *motion*, and *number*. He enlarges to some extent upon this subject in a supplement to his memoir, into the details of which we cannot now enter.

The dangers which threaten travel by rail and sea, and the disasters resulting from mistakes of the color-blind with regard to colored signals, were clearly understood and distinctly expressed, and the measures to be taken to avoid them plainly proposed more than twenty years since. If, therefore, it is now asked, as would be natural, to what practical results all this has led, we might reasonably expect, especially when we recall the attention that Wilson awakened on the subject amongst his contemporaries, that an important reformation for assuring public safety would long since have been accomplished not only in England, but in every civilized country. A mere glance over the existing condition of things, however, reveals the fact that the answer is not satisfactory. The only practical result mentioned by Wilson in his work as a result of his writings, is the resolution of the Great Northern Railway Company that the entire *personnel* must in future prove themselves free from this defect of the chromatic sense before entering the service; and, as Wilson says, the public is indebted for this wise measure to one of the directors of the company, Mr. Graham Hutchison, whose attention was called to Wilson's works by Dr. Mackenzie, of Glasgow. We see by this that the numerous articles written by Wilson before publishing his views and experience in full had aroused public attention to an interesting phenomenon in the scientific world, but had not led to any practical application, except in the one case in which a physician had succeeded in personally interesting one of the directors of a railway company in the question. We know not how far other administrations have followed this example. It is very probable that this measure has not been adopted by a single company in Dalton's country, where color-blindness was discovered in the first place, and where it was studied with so much care that England was long regarded as the veritable land of this anomaly.

It would appear then that no considerable change has taken place in the matter since Wilson's time. With regard to the English navy, we still lack positive information.

With regard to France we are more fortunate. For a long term of years, Dr. A. Favre, of Lyons, was occupied with the practical side of this question, and made different investigations into the perception of colors, especially amongst the employés of the Paris-Lyon-Mediterranean Company, of which he was for a long time one of the consulting physi-

cians. He then proceeded to make an examination of soldiers, sailors, and students. The information we are about to give is principally derived from Dr. Favre's pamphlet, which he kindly sent us.

We will give a brief statement of his statistics, his method, and his idea of color-blindness, and then his propositions for practical measures.

In relation to the frequency of color-blindness amongst the *personnel* of railways, Dr. Favre tell us that out of 1,196 candidates examined by him from June, 1864, to December, 1872, thirteen were red-blind and one green-blind (1.17 per cent.); but out of 728 employés of the same line examined in 1872 and 1873, he found not less than 42 cases (5.76 per cent.) of color-blindness more or less pronounced, and that although 276 amongst them had previously submitted to an examination for the same defect. During a subsequent examination, from July, 1873, to October 1, 1875, he discovered, amongst 1,050 men from eighteen to thirty years of age, nearly all formerly soldiers, not less than 98 color-blind (9.33 per cent.). The increasing proportion of color-blindness at each series of inspection must be attributed to the modifications introduced into the method and diagnosis, owing to which a comparatively much larger number of cases has been classed under the head of color-blindness. This large proportion is easily explained by the method and manner of making the diagnosis. Dr. Favre's method, which he has developed from year to year, consists in this: he presents to the subjects to be examined wool of different colors corresponding to those of the spectrum, *red*, *yellow* (including *orange*), *green*, *blue* (including *indigo*), and *violet*, and demands the name of each of these colors. All who are at fault about them are pronounced color-blind. He regards also as such those who hesitate, and who, when the test is repeated several times, give to a color sometimes its own name and sometimes another. And yet, Dr. Favre thought it his duty to correct the result obtained at the last examination: from the 98 cases, he withdrew 29, who hesitated only in the designation of the colors, and 8, who, after repeated tests, corrected their preceding mistakes; the proportion falls by that from 9.33 to 5.8 per cent.

On two points, Dr. Favre has in his works announced new views, and whether they ought to be accepted or merely left to gain supporters, they are of a nature to produce consequences of great importance in the practical world. In fact, it has invited especial attention on one hand to *acquired* color-blindness, which is quite common, according to his pamphlet, on the Paris-Lyon-Mediterranean line, and results from various causes. On the other hand, he asserts that *congenital* color-blindness is not incurable, but can be remedied by means of assiduous and systematic exercise in colors.

The practical measures demanded by Dr. Favre, in accordance with his views and experience and that of his fellow-laborers, with regard to color-blindness, might be embodied in the following terms: an examination of the chromatic sense, obligatory upon all candidates for

railway employment, and upon those already in service; exclusion from active service of all who cannot distinguish red; especial examination of all employés afflicted with contusions or wounds on the head, or recovering from a serious illness; examination of drinkers and smokers; and, finally, a periodical examination of the entire *personnel* in active service; these last measures having reference to acquired color-blindness. These principles apply equally well to sailors. In behalf of his views on the curability of acquired color-blindness, in which he seems more and more interested, Dr. Favre earnestly urges the introduction of systematic exercise in colors in schools, in the army and navy, and on railways.

It is readily seen that these views, and the measures based upon them might have very considerable practical consequences; in fact, if they were proved by a decisive test, we would have the best and most radical means of preventing all the inconveniences and dangers that color-blindness might occasion. But, on the other hand, if the ideas of our honorable colleague prove to rest on but slight foundation, as is generally admitted so far, and as we ourselves believe, it is to be feared lest through an actual improvement in the chromatic sense, on which these measures depend, we might be led into error as to the ability that the color-blind often acquire by practice in designating the colors of common objects accurately by conjecture or the help of other characteristics, and, lulled into a false security, neglect the measures that should and might be taken. We are far from asserting that Dr. Favre's opinion on this point may have already exercised such an influence, but we cannot refrain from mentioning a circumstance, which, at all events, would not contradict such a supposition. In fact, Dr. Favre tells us that in 1875 the Academy of Sciences and Letters at Lyons voted resolutions calling the attention of the ministers, and amongst others that of the navy, to Dr. Favre's publications, and especially his request that sailors should be educated and exercised in colors. We do not know whether this decision has been put into practice, but we have no reason to doubt it. But, on the other hand, we learn, from special information, that up to the present (January, 1877) no examination of the chromatic sense has been exacted of those desiring to enter the French navy. Nevertheless, Dr. Favre's labors and his practical efforts in the cause of color-blindness have awakened genuine attention in France and Belgium. He tells us himself, also, that the greater part of the precautionary measures in use on the Lyons railway from 1857 have been since introduced on other lines, and quite recently on the Belgian railways. Moreover, Dr. Favre's example has enlisted the interest of several physicians in this cause. One of the most distinguished, Dr. Féris, surgeon-general of the navy, has written a memoir on the importance of color-blindness to navigation. This memoir describes an examination, by the author, of 501 sailors, amongst whom he discovered 41 cases, more or less affected with this anomaly of the chromatic perception, that is to say, 8.18 per cent. This large proportion is explained by the fact that Dr. Féris finally employed

the same method and made the same diagnosis as Dr. Favre, and nearly the same classification, with slight modifications.

The foregoing seems to show that the question is now exciting attention in France, and this owing to the activity of a single individual. It is obvious, however, that although Dr. Favre may have succeeded in introducing measures insuring the communications against color-blindness amongst the employés of the line to which he was himself attached, or those of other lines, no reform has been *generally* recommended or introduced on the French railways, and that absolutely no measures have been taken in the navy. Besides, it is evident from certain passages in Dr. Favre's pamphlet and from his opinion of the curability of congenital color-blindness, that the principles applied, where a control has been introduced, have not been particularly rigorous. As to the elimination of the color-blind *personnel*, it might with certainty be concluded that no rigid rule has been followed; from the fact that those only are discharged from active service who "cannot or only partially can distinguish red, and are consequently dangerous," and the fact that of the forty-two color-blind subjects detected by Dr. Favre in one of his examinations, nine only were removed from active service.

In Germany, where an interest in color-blindness has been lately excited in many quarters, but little is presented in regard to the control of this defect on railways and in the navy. We can supply only a few data capable of throwing any light upon the state of the question there.

In an article on the works of Dr. Favre, Mr. Blaschko points out the importance of seriously making the sense of color amongst the *personnel* of railways an object of official scrutiny and control, according to Dr. Favre's plan.

Dr Stilling in 1875 gave us still further information in an account of a method proposed by him for discovering color-blindness by means of colored shadows. "Here also in Germany," says he, "several railway companies have directed their attention to this subject (color-blindness), and the time is probably not far distant when investigation amongst railway *personnel* and others will be undertaken *ex officio* and *en masse*." We do not know how or in what measure this prediction may be realized, but inasmuch as the late movement in Sweden was regarded by the German papers as a new and extraordinary phenomenon, and as, moreover, one of the most eminent physiologists of Germany writes us that no general measures have been adopted with regard to it in that country, we may conclude that no practical reformation on the subject has been generally introduced there.

We hear from Holland that measures with regard to this defect are now on the road to execution.

A rapid glance over the development and existing state of this question in Sweden cannot be void of interest. In what is called the Lagerlunda case or trial, instituted in consequence of a railway accident, of which Lagerlunda in Ostrogothia was the theater, November 15, 1875,

and which at the time intensely excited public attention, testimony was adduced which led me to suppose that color-blindness was one of the principal causes of the disaster. This impressed me with the idea that official scrutiny and control should be exercised over the sense of color amongst railway employés. Without knowing what had been done or written with reference to this in other countries, I considered it my duty to take the initiative. After convincing myself that the steps to be taken should consist, with the preservation of the existing system of signals, in eliminating from the railway service all employés afflicted with color-blindness, or at least those with certain kinds and degrees, I regarded it, first, of the highest importance, to have a practical method which should render the discovery of the color-blind rapid and certain, without incurring heavy expense or requiring extensive preparations, and in consequence to be able to examine easily a considerable number of individuals. Then it seemed to me essential to endeavor to interest the high functionaries at the head of the railways personally in the matter.

As regards the method, I had already found one purely theoretic, which, while in agreement with that of Young-Helmholtz, proved to be practical in the examination of the color-blind. But this method was only intended for discovering the types of partial color-blindness (complete, according to the theory), but not the form of blindness I had ascertained by the perimetrical examination of the colored visual field, and defined under the name of incomplete color-blindness. The method received accordingly a new practical aim, and it became necessary, in consequence, to render it more accurate, and especially to make a trial of it by an examination of the masses, so as to determine, by experiment, the practical value of the method, and form an idea of the amount of color-blindness in our country, of which no one had the slightest conception. The desired occasion presented itself in the month of June, 1876, and I am indebteded to the politeness of Major-General Von Knorring and Major Rudbeck for permission to examine 2,220 men belonging to a regiment of infantry, cantoned in Upland (standing army and militia), and to the dragoons of the guard (militia). The method proved to be capable, in its extraordinary simplicity, of perfectly answering the end in view with reference to rapidity and accuracy. The examination of each man required, on an average, one minute, sometimes more and often less; and with the improved form we had given the method, we also discovered, with accuracy, every individual incompletely color-blind. With regard to the knowledge acquired by this examination of color-blindness amongst the population of the province, we found that out of 2,220 men eleven could not distinguish red, seventeen green, one violet (?), and thirty-one were incompletely blind, according to the classification I had used. There were, then, in all, sixty color-blind, or 2.7 per cent.—The instances of a feeble sense of color are not included in this.

On the 14th of July, of the same year, I had an opportunity, before a congress of Scandinavian physicians assembled at Gothembourg, of giving an account of the method, of stating the results obtained by its use, and, besides, of expressing my views on the necessity of taking measures, on a large scale, for the detection of color-blindness, especially amongst railway employés. It resulted in the congress unanimously resolving that it was necessary to make investigations for the detection of color-blindness: 1st. Amongst employés of railways; 2d. Amongst pilots, light-house keepers, and sailors in general; and 3d. In schools. During the session of the congress I had an opportunity also of proving to the physicians the practical utility of the method by examining, in their presence, and with the permission of Colonel Carlsohn, 100 men of a regiment of artillery from Gothia, amongst whom we found four color-blind, namely, one red-blind, one green, and two incompletely blind. Besides, on the same occasion, we discovered amongst the medical members of the congress one green-blind, and amongst the audience one red-blind.

I was then advised to apply directly, in person, to the directors of railways. Thanks to the press, which had attentively followed up the debates of the Gothembourg congress, the question had reached the public. It naturally became an object of attention to railway officials, although received by a greater portion of them with a certain mistrust, seeing in it the result of a scientist's imagination or an overwrought solicitude, rather than a matter of practical application for the benefit of railways. "If color-blindness really exist," they said, "it cannot, at any rate, be amongst the employés, or it would undoubtedly have been remarked; especially must this be the case amongst the engineers and conductors, as they rise from inferior grades, and consequently have amply proved their ability to distinguish signals." It was therefore of extreme importance to endeavor to obtain at once positive assurance on this point. The opportunity soon presented itself. Mr. Jacobsson, superintendent-in-chief of the Upsala-Gefle line, invited me to accompany him in a tour of inspection to examine all the employés under his control. The trip was made in a special car; we left Upsal the 7th of September, and, to make our inspection, halted at every station and gate-keeper's and guard-house. In brief, we stopped at every place where an employé could be found. The investigation was concluded at Gefle, the 8th of September. The entire *personnel*, men and women, numbering 266 individuals, was examined. We discovered amongst these thirteen color blind men, that is, 4.8 per cent.; six were completely green-blind, and seven incompletely blind. They were distributed as follows, with reference to their functions: one station-master, one engineer, two conductors, one foreman, two workmen (one a supernumerary), two overseers (one a supernumerary), two way-guards, one porter (messenger), and one journeyman engineer. Immediately after the examination, the general superintendent discharged all who were completely green-blind.

This first inspection was in many respects very interesting. It showed

that the method of inspection could be used and was expedient for railways. Moreover, it proved that there really were color-blind in almost every grade of service of a Swedish railway, and this without there having been the slightest suspicion of it, which confirmed my opinion of the utility and importance of enabling those employed on railways to convince themselves *de visu* of the nature of color-blindness and of its practical value to railways.

Relying upon the experience I had just acquired, I wrote, September 25, to the royal directors of the state railways, and called attention, amongst other matters, to the necessity of establishing a systematic control over the sense of colors amongst railway officials, and requested at the same time permission, in the presence of the directors, or a person designated for the purpose, to examine the officials attached to any railway whatsoever for the purpose of convincing the directors, in a practical manner, of the true nature and importance of the question. At this time the directors had already issued orders that as incapacity to distinguish primitive colors closed the avenue to railway employment, the physicians attached to the different lines must examine all applicants, and that heads of sections must afterward examine into whether any of their subordinates were incapable of distinguishing these colors, in the use of flags and ordinary signal-lights, in any way which seemed proper to them. On the other hand, however, debates and experiments on color-blind individuals, at the Physiological Institute of Upsal, had enabled me to succeed in interesting in the question several persons attached to railways, and amongst them all the directors of the Upsal-Gefle line.

In another letter to the royal directory, dated October 8, I invited the members to be present at one of these experiments, to be able to form a better judgment of the question. Two engineers of the railway presented themselves October 11, and on the 13th the chief director, Mr. Troilius, came in person. From this day success seemed assured. As early as October 16, the directors ordered that a physician from each district, and as many more as should desire, should assemble at my office at an appointed time, to acquaint themselves with the methods that I would explain to them relative to the examination of cases of color-blindness amongst the railway *personnel*. In consequence of this, at the appointed time, October 24, twenty-six physicians attached to railways assembled in the Amphitheater of Physiology at Upsal, and also thirty-two individuals employed on railways, amongst whom were the heads of nearly all the lines belonging to the private companies of the country.

November 9, the managers directed the physicians of the lines to proceed gradually, and according to my method, in the examination of all the men then employed on railways. Those of the physicians who did not understand this method, added the circular, should study it, either with me, or with one of the physicians who had been

present at my lectures on the subject; and finally the superintendents must send a report of the result of this examination, suggest measures to be taken, and in certain cases apply those that circumstances might require. In this way the reform was actually introduced on the railways of the state. The example was soon followed by the private companies (we do not know of a single exception), and although all the reports have not been returned (February, 1877), and consequently the result is not yet perfectly known, we might assert that the examination itself is finished everywhere, in an almost if not entirely thorough manner. Every case during the examination pronounced doubtful in the diagnosis, or where doubt existed about the measures to take with regard to it, has been reported to me. Sweden is consequently the first and only country, as we see, where the control in question has been generally adopted, and applied according to determined principles.

We have enlarged to some extent on the manner in which this matter has been successively accomplished in our country, not simply to give our experience on the subject, but rather that such details seem to us to elucidate the question occupying us. This will be clearly evident if we compare other countries with our own with regard to this. Let us recall the following facts: In England, color-blindness has been known for a century, and for more than twenty years a strict control over the sense of color amongst railway employés and sailors has been demanded. In France, a physician attached to a railway has been for a long time interested in color-blindness amongst its employés, and has been endeavoring for at least three years to introduce a general control on railways, in the navy, and in schools. Finally, in Germany, color-blindness has been for a long time a subject of scientific study, where the necessity of a control of the railway officials has been urged by a number of people of late years. Well, we have seen that in spite of all this, not one of these countries has yet decreed or introduced a general control on railways and in the navy. In Sweden, on the other hand, where color-blindness had scarcely been mentioned until the last few years, and where a proposition to examine railway officials was only publicly made July 14, 1876, and referred to directors of railways September 25, of the same year, this important reform may be already regarded (February, 1877) as actually and thoroughly established, in all essential details, on the entire system of railways throughout our country. To complete our data, it may be added that since November 12, 1876, the king has issued orders that, at the time of a general review of the fleet, every man should be examined with reference to color-blindness. This result is so truly remarkable that we cannot refrain from endeavoring to discover the probable explanation of the unexampled rapidity with which it has been reached in our country. The explanation does not seem to us difficult. In our opinion, it is chiefly owing to two circumstances: one is the method employed, which is not only accurate, as well as simple and rapid, but effects so palpable a result that the most skeptical observer

is struck by it; the other circumstance is the manner in which the knowledge of the method, as well as the principles for the introduction of an official control, has been spread throughout our country. This publicity was not reached in the usual way, through the medium of books, but by oral exposition, practical application, and *de visu*. Our idea is confirmed by the fact that this personal influence is recognized in the cases brought to our knowledge in England and France, where the scrutiny and control over the sense of color amongst the *personnel* of railways has been introduced, particularly on the Great Northern Railway of the first-named country, and the Paris-Lyons-Mediterranean line. But even without this support, our experience would sufficiently convince us that it is important, if not necessary, to explain the question orally and *de visu* to the physicians, and especially to railway employés. Speech, in such cases, has an undoubted advantage, and our experience of the last months of 1876, when the Amphitheater of Physiology at Upsal was often the resort of physicians, railway officials, and individuals afflicted with color-blindness, proves to us that this kind of communication, especially in such a case as that now before us, undoubtedly exerts a more powerful influence than the best written book.

The warm interest with which the question has been followed up by the journals is too important a circumstance to be forgotten. Not only has this kept the public on the alert, but the movement begun by us has been continued in other countries. Immediate effects were visible amongst our neighbors. In Finland, Dr. L. Krohn, who acquainted himself by correspondence with the method and principles used in Sweden, has already examined the railway officials of his country. A locomotive and ambulance were placed at his disposal for examining the *personnel* the whole length of the line. All was accomplished in twelve days. He discovered amongst twelve hundred individuals examined, sixty color-blind, that is, 5 per cent. They were distributed as follows: four red-blind; twenty-five green-blind; and thirty-one incompletely blind.

We have as yet heard of no results from our method in Denmark and Norway, but the question is there under serious examination, as the Physiological Institute of Upsal has been visited on different occasions by two Danish physicians, Dr. Slidelin and Dr. Fontenay, sent by the railway managers of Zeeland, and by Mr. Hagen, assistant at the Physiological Laboratory of Christiania, sent by the Medical Board of Norway at the suggestion of Professor Worm-Müller. I have thus had the pleasure of explaining to them the method of examination as well as the practical principles and rules I propose to communicate in this work.

II.—THE NATURE OF COLOR-BLINDNESS.

It is not my intention to treat this question in a thorough manner, but simply to mention what is essential to the practical end in view.

It has been known for a long time that every one does not possess

the power of distinguishing colors in the same manner, and that some exhibit a divergence of such a nature as to excite surprise and amusement. The confusion of green and red is very common. But, in many instances, the difficulty consists merely in discriminating between delicate shades, while the principal colors are easily distinguished. How shall we explain all this; how find the relation existing between the normal sense of colors and the abnormal; and where must the limit be drawn?

1.—THEORETICAL SKETCH.

Every one knows that a radiant body creates, throughout the ether which surrounds it, undulations which are propagated in every direction. When these undulations—whether they proceed directly in right lines from the radiant body, the sun for example, or whether they are reflected by some intervening body encountered in their course—come in contact with special organs of sense, they produce certain corresponding changes, which, in their turn, excite certain perceptions in our mind. If the undulations come in contact with our skin, we experience the sensation of heat; if they strike the retina, that of light. It is consequently our own brain that produces both light and heat, resulting from certain changes that take place in our organs of sense (the retina or the skin), although by these names we designate the external cause, when we say that the rays of light and heat proceed from the incandescent body. Nevertheless, to thoroughly understand this fact it is necessary on the one hand to distinguish between light and heat in an objective sense, which are virtually the same thing, that is to say, undulations of the ethereal medium: and, on the other hand, between light and heat in a subjective sense, which are sensations of an altogether different kind. We have, in the first place, here to consider our perceptions, and as their most immediate cause is found in a modification or activity of our own organs of sense, whatever be the external cause, it is clear that we must seek the explanation of all luminous phenomena in our special organism—the optic nerve; comprehending by that term the retina, the optic nerve, and those portions of the brain with which they communicate.

If all the undulations of the luminous ethereal medium were exactly of the same nature, or, on the contrary, if all the elements of our optic apparatus reacted in the same way on every kind of undulations of the ethereal medium, we could with difficulty imagine sensations of light of a different nature. Every specific activity of our apparatus of the optic nerve would produce a perception of light which would vary in degree, but not in quality. We could have no conception of, according to the cases, a light of different kinds, that is to say, of color. But, on the one hand, the science of physics teaches that the undulations of ether are of various kinds, differing in the rapidity, and consequently in the length of the waves; and, on the other hand, the subjective qualities of light, or our perceptions of color, fall within the range of our daily experience.

It belongs to theory to discover the law regulating these two factors. All the qualities of light must depend upon functional differences of the elements of the organ of the optic nerve. A necessary alternative is, either this organ has but one kind of elements, and then different kinds of undulations of the ether induce it to act under different forms, or else there are several kinds of elements or terminal organs in the retina or in the brain, which always act respectively in the same way, while differing from each other. This latter hypothesis accords better with all we know otherwise of the physiology of the nervous system, and is virtually but J. Müller's principle of the specific energies of the senses applied in detail to the sense of sight. It is also on this last hypothesis that the Young-Helmholtz theory is based.

The following is the principle upon which this theory explains the qualities of light or colors. When one kind of element alone is excited or set in motion, or when all are simultaneously excited, but one in a higher degree than the rest, our sensation takes hold of that element as the quality of the light, as the colored light or color, and particularly the cardinal or primitive color, which corresponds specifically to the excited element. If there are several kinds of elements, and only two of these are excited or more excited than the rest, we see the light colored, but of a color which constitutes the combination of the two colors corresponding to the excited elements. It is clear that the principle on which this reasoning is based gives room for the admission of as many different elements, and, consequently, primitive colors, as could be desired. At all events, it results from the principle that when all the kinds of elements, whether there be one or several, are excited simultaneously with the same force, there is no possibility of perceiving the quality of light. We then see but a light in general, in contradistinction to the absence of light or darkness; in other terms, we see a colorless light, or, as it is called, a *white light*, and incorrectly a *white color*. It follows therefore that when one element is principally excited while the rest are also excited, but in a less degree, the perception of the specific quality of the light is feeble in proportion to the degree of excitation of the other elements, since this effect of their excitation must be, in short, like a mixture of colorless light, or white relatively to the color in question.

Let us now see how the Young-Helmholtz theory applies the principle we have just explained. It recognizes three cardinal colors, *red*, *green*, and *violet*, and consequently three kinds of corresponding elements in the organ of the optic nerve; elements respectively perceiving red, green, and violet. When the perceptive element of red is excited alone, or in a greater degree, we experience the sensation of red, and so on. Different kinds of undulations of the ethereal medium excite, in different degrees, the different elements, but in such a way, however, that all excite in some measure each of these elements.

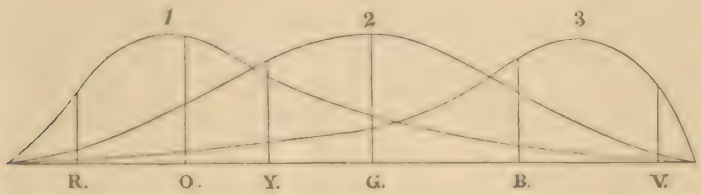
Without attempting, from a scientific point of view, to explain the dif-

ferent kinds of objective light in the length of the wave, in the practical course we are pursuing here it is much more convenient to designate them by the effect they exert on the normal sense of colors. With this explanation we will then proceed to speak of red, green, and violet light, and so on, meaning those ethereal waves which differ in length, in duration of undulations, in refrangibility, etc.

The easiest and most convenient means of describing the relations existing between the kinds of objective light and the excitability of the different elements, or, in other words, of the different kinds of subjective light, will be to construct a diagram in which the curves indicating the different kinds of light will be traced on an abscissa according to the order in which they are presented in the solar spectrum, and those which indicate the excitability of the respective elements, or rather the intensity of the sensation of colors, will be expressed by the ordinate. To save space, and more easily to comprehend the whole, we have drawn the curves of intensity of the different elements on the same abscissa, which consequently serves for each one of them.

Figure 1 represents this diagram, showing the normal sense of colors. The spectral colors are here found placed horizontally in the natural order, beginning with the red (R.), and finishing with the violet (V.); the three curves of excitability, namely, 1st, that of the organ perceiving red; 2d, that of the perceptive organ of green; and, 3d, that of the organ perceiving violet; these curves indicate the manner in which the different systems of waves of solar light act on each of the three elements sensible to light.

FIG. 1.



According to these curves, the homogeneous *red*, from the extremity of the spectrum to beyond the orange, affects the perceptive elements of red strongly, in a much less degree those of green, and still less those of violet. From this results the sensation of *red*, which is transferred more and more into orange in proportion to the increase of the excitation of the perceptive elements of green. Homogeneous *yellow* intensely excites, and almost in the same degree, the perceptive elements of red and green, while only feebly affecting the perceptive elements of violet. Hence, the sensation of yellow, which is a combination of red and green. *Green* light strongly excites the perceptive elements of green, and very feebly and almost equally the two other elements. Hence, the sensation of green. Homogeneous *blue* excites quite strongly and almost equally the

perceptive elements of green and violet, but feebly those of red. Hence, the sensation of blue, which is a combination of violet and green. *Violet* light powerfully affects the perceptive elements of violet and feebly the two others. Hence, the sensation of violet.

These curves enable us to explain easily the colors of the spectrum by the theory. We find in what proportion each one of the three fundamental perceptions enters into it by measuring the vertical distance from their place on the horizontal line (abscissa) to the corresponding points of each of the three curves. It is then seen that there is no color of the spectrum into which but one primitive color enters exclusively. The two others also furnish their contingent. No one is therefore perfectly "saturated." They are more or less spread with white, and green is the least sensibly "saturated," or more whitish. The curves also show us that yellow and blue are at the same time whitish colors, and the most intensely luminous in the whole spectrum. When we again add that a color "saturated" in almost the same degree as the other spectral colors, proceeds from the homogeneous combination of red and violet, that is to say, purple, and its whitish shade, pink, we shall have said all, theoretically, that we have to say in relation to the normal chromatic sense.

To explain the abnormal sense of colors by the theory of the normal, we can, in advance, conceive various possibilities. Let us suppose that one of the three fundamental perceptions is wanting, or that one of the primitive colors is absent; it is clear that the whole chromatic system will be upset. It is evident, therefore, that this system must be completely different, according to the absence of one or the other of the three primitive colors. It is virtually just in this way that it has been attempted to explain cases of a strongly marked defect in the chromatic sense, or genuine types of blindness to color, found in real life. The term *color-blindness* has been justified by this, as it indicates in each case a genuine blindness to one of the cardinal colors. In this way, therefore, we distinguish, according to the kind of element wanting, three classes of blindness:

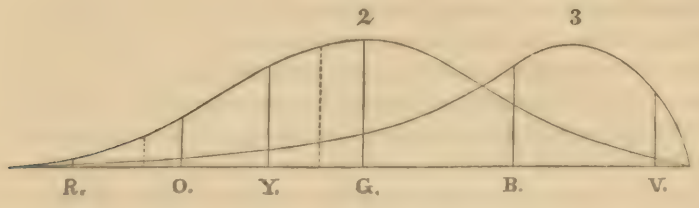
1st. Red-blindness.
2d. Green-blindness.
3d. Violet-blindness.

We shall see that the Young-Helmholtz theory, as we have explained it far from being contradicted, as has been recently claimed, by the phenomenon of color-blindness, finds in it, on the contrary, a support, and this theory most certainly furnishes the best guide for attaining the practical end in view for which we intend to use it. Let us, in the first instance, cast a rapid glance over the different kinds of typical and complete blindness to colors, as their features are presented by the theory. This sketch will be singularly facilitated by the use of the same kind of curves employed in illustrating the normal sense of colors.

1. According to the theory, blindness to *red* is due to the absence or paralysis of the organs perceiving red (fig. 2). Red-blindness has then

but two fundamental colors, which, adhering strictly to the theory, are *green* and *violet* (blue according to Maxwell).

FIG. 2.



The curves distinctly show what aspect the various kinds of lights of the spectrum must have for the chromatic sense such as the one we have in view. We will give a short list of them, according to Helmholtz, by designating here the different kinds of lights, as we did before, that is to say, by using terms borrowed from the impressions they produced on the normal chromatic sense; the comparison will not be without interest.

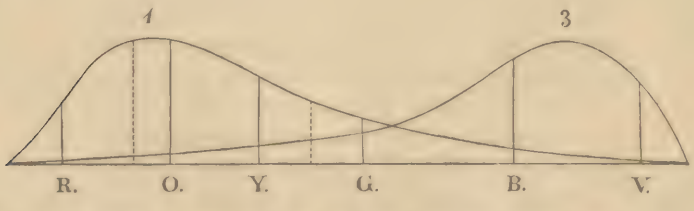
"Spectral red, which feebly excites the perceptive organs of green, and scarcely at all those of violet, must consequently appear to the red-blind a '*saturated*' *green of a feeble intensity*, more 'saturated' than normal green, into which a sensible portion of the other primitive colors enters. Feebly luminous red, which affects the perceptive organs of red in a normal eye sufficiently, does not, on the other hand, sufficiently excite the perceptive organs of green in the red-blind, and it, therefore, seems to them black. Spectral *yellow* seems to them a *green* '*saturated*' *and intensely luminous*, and as it constitutes the precisely saturated and very intense shade of that color, it can be understood how the red-blind select the name of that color, and call all those tints that are properly speaking green, *yellow*. *Green* shows, as compared with the preceding colors, a more sensible addition of the other primitive colors; it then appears, consequently, like a more intense but whitish shade of the same color as yellow and red. The greatest intensity of light in the spectrum, according to Seebeck's observations, does not appear to the red-blind to be in the yellow region, as it does to the normal eye, but rather in that of the blue-green. In reality, if the excitation of the perceptive organs of green, as it was necessary to assume, is strongest for green, the maximum of the total excitation of the red-blind must be found slightly toward the blue side, because the excitation of the organ perceiving violet is then increased. The white of the red-blind is naturally a combination of their two primitive colors in a determinate proportion, a combination which appears blue-gray to the normal sight; this is why he regards as gray the spectral transitition colors from green to blue. Then the other color of the spectrum, which they call *blue*, preponderates, because indigo-blue, though somewhat whitish, according

to their chromatic sense is to them, owing to its intensity, a more evident representative of that color than violet."

This description of the manner in which the red-blind forms a conception of the different kinds of light of the spectrum is assuredly a conclusion logically deduced from the theory, but it accords so well, at the same time, with the experience acquired in examining the color-blind, that this might perfectly serve to support and corroborate the theory. We will simply add a point for our especially practical purpose, or rather emphasize one point of this theory. In fact, it is clear that a red and green light especially excite one and the same element in the red-blind. A ray red and green, or an object red and green, to the normal sense, must seem fundamentally to the red-blind to be the same color, and if, in especial cases, he knows how to discriminate, his judgment is simply guided by the intensity of the light. The intensity of light is much more feeble, as shown by fig. 2, in red than in green. If then a red-blind individual finds that a red and green tint are exactly alike, it is necessary that the green be to the normal eye much less intense than the red. This is distinctly shown by the vertical dotted lines between R. and O., and also between Y. and G., in fig. 2, and this is entirely confirmed by experience.

2. *Green-blindness* derives its origin, according to the theory, from the absence or paralysis of the perceptive elements of green. The green-blind has therefore but two fundamental colors, that is—still closely adhering to the theory—red and violet (blue according to Maxwell). The spectrum for green-blindness should be, according to the theory, constructed in the following manner:

FIG. 3.



The spectral *red*, which strongly excites the perceptive organs of red, and but very faintly those of violet, must therefore appear to the green-blind as an extremely "saturated" red, but of a light somewhat less intense than the normal red, which is comparatively more yellowish, as green forms a part of it. The spectral *orange* is again a very "saturated" red, but much more luminous. Yellow is undoubtedly a more intensely luminous red than the spectral red, but, on the other hand, more whitish, because a sensible portion of the other primitive color enters into it.

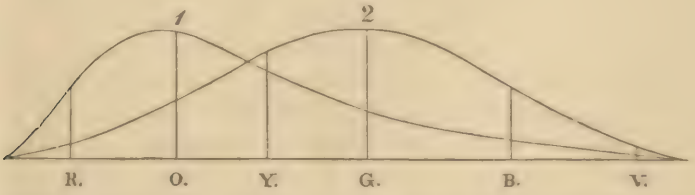
Green, with its shades inclining to yellow and blue, ought, correctly speaking, to be a "saturated" purple and with a mean intensity of

light, but it is the white (gray) of the green-blind, for it is composed of almost equal parts of the two primitive colors.

The *blue* is an intense violet, but a little less "saturated" than indigo, which is more strongly luminous and more "saturated." Violet is a little less intense, but more "saturated" than normal violet. The tints most luminous and at the same time most "saturated" which must constitute the types of the primitive colors of the green-blind are orange or its immediate neighbor in the spectrum, red, and indigo-blue. Now orange is a color which, in ordinary language, especially amongst the uncultivated and unpracticed, is indiscriminately called red and yellow; this fact explains why the green-blind denominate their first fundamental color sometimes "red" and sometimes "yellow." We will add to this description the same remark made about red-blindness. In green-blindness the same organ is also found affected by spectral red and green light. Red and green are then perceived by the green-blind in the same way, or, in other words, are to him in fact exactly the same color. In cases where he succeeds in distinguishing them, it is by the aid of the intensity of the light; but with regard to this intensity of light, it is the opposite of what occurs in the case of the red-blind. A green tint which to the green-blind must appear exactly like a red one, to a normal sense of color must be sensibly more luminous than red. This is shown by the dotted vertical lines between R. and O. and also between Y. and G. (fig. 3), and is confirmed in every respect by experience.

3. *Violet-blindness* (or blue according to Maxwell) is due, according to the theory, to the absence or paralysis of the elements perceiving *violet*. The two primitive colors of the violet-blind are then, according to theory, *red* and *green*. The spectrum of the violet-blind must in consequence be represented as follows:

FIG. 4.

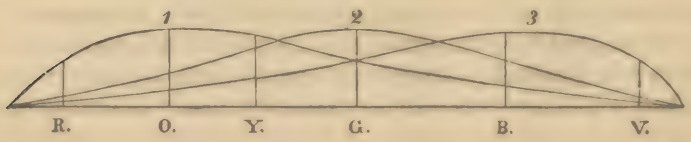


The *red* is a purer red color (not yellowish) than normal red, but still less "saturated"; the more it inclines toward orange the more strongly luminous it is, but is at the same time less "saturated," more whitish. The *yellow* is, as it were, a combination of almost equal proportions of the fundamental colors that form white. *Green* is a strongly luminous, but whitish green, which in tending toward the blue, becomes more and more "saturated," so that greenish blue must be the type of these hues. The *blue* is a green of moderate luminosity and strongly "saturated", and *violet* is green very feebly luminous, but also "saturated" in a much higher degree than the normal. A violet strongly luminous is sufficient

to induce this green, but a feeble violet, although very sensible to the normal eye, is black to the color-blind in question.

It is plain that the violet-blind, whose primitive colors are red and green, do not confuse these colors. This kind of blindness, from the experiments made so far, must be very rare. For our part we have not succeeded in discovering more than two cases agreeing quite exactly with the description given by the theory, while the first two kinds are comparatively very common. In order to be abnormal it is not necessary that a sense of color should completely fulfil the conditions indicated in the types we have just described. We might perfectly conceive a resultant, not of an absolute absence or of a complete paralysis of one kind of perceptive elements, but solely of a comparatively very low excitability, or, if preferred, of a much more limited number of one kind of elements, acting on the retina, as compared with the two other kinds. It is very easy to construct curves in conformity with this idea, and not less easy to arrange in this manner a continuous series of transitions and gradual forms between one kind ot complete color-blindness on one side and the normal chromatic sense on the other. This kind of defective vision might be called *incomplete color-blindness*, to distinguish it from complete, as we have just characterized the three different kinds. Our experience has taught us that the intermediary forms agreeing with the data given above are met in large numbers in practice and of very different degrees. These are the forms we designated under the common appellation of *incomplete color-blindness*, but we can according to the theory still conceive other forms of a defective sense of color. There is one, amongst others, which has at command only one of the three kinds of elements. Such a sense of sight is not properly a chromatic sense. For it, there exists no specific difference in light, that is to say, no color. Every kind of light here acts as if on one element alone. This is why the single perception of differences of intensity of light (quantity), but not of differences of color (quality), is possible. This condition may then be designated under the name of *total color-blindness*. Several cases have been mentioned from time to time, but we have not succeeded in finding a single one, and it may well be questioned whether such a case has actually existed. We may also conceive that another form of a defective sense of color arises from the three kinds of elements being uniformly of moderate sensibility. We are able to trace the following diagram (fig. 5), by which the three curves simultaneously approach the abscissa, and are flattened in such a manner that the vertices disappear the first.

Fig. 5.



As is readily observed, green is then precisely the color which, being ordinarily the most whitish of the primitive colors, is the first to lose its quality of "saturated" color, and shades into gray. This must then be the exact scheme of pathological color-blindness, according to the theory. In fact, we have found in our examinations a large number of cases perfectly harmonizing with this scheme. We have, therefore, classed them under the head of *incomplete color-blindness;* and this from essentially practical reasons. To define their nature according to the theory, it is necessary to regard them as a particular variety, which we shall call a *feeble sense of colors.* We are not of course able to decide how far defects of this kind should be considered as having a pathological origin, or whether they are ever congenital. For this determination a much wider experience in this particular department than we now possess is requisite, for reasons to be given hereafter. This kind of defect in the sense of color leads, if we fancy it carried to its highest degree, or in such a condition that all the elements lose sensibility, to the complete absence of perception of light, that is to say, to blindness, strictly so called. Every defect in the sense of color must then proceed either from a sensibility anomalously reduced to a complete paralysis of one or several kinds of elements, or from a number relatively diminished in sensibility to the complete absence of one or several amongst them.

The experience acquired by an examination of colors in different parts of the visual field elucidates our theory of color-blindness, while at the same time having a practical value. The following is the manner in which this examination is conducted: the eye is fixed upon an immovable point; a colored object—for example, a colored paper one or two centimetres (two or four-fifths of an inch) square—is slowly passed from the side of the visual field toward the fixed point. This experiment is performed still better by means of a special instrument, Förster's perimeter. We then find that the colored surface, of any color whatsoever, appears completely colorless at the extreme periphery of the visual field. Surfaces of different colors exhibit only variations in intensity of light, not in color. The ground on which the surface appears plays here an important part; since every time our visual sense perceives the light and color of an object, it partly depends upon the comparison with that which surrounds it. Thus a colored surface seems to us, in this part of the visual field, black or gray on a light ground, and gray or white on a dark. If while following the same direction, the colored object is carried within the region which surrounds the rest of the visual field, like a belt of greater or less width, we begin to see the colored object, but not always in its natural color. Two colors alone, yellow and blue, retain their natural colors. All the others have the appearance of one of these colors, consequently yellow or blue. It is only after the colored object is carried a little farther toward the fixed object that it is seen in its natural color. Consequently we normally see colors only in the middle of our visual field, within a compass extending in a more or less eccentric manner in every direction from the fixed

point. Outside of the central field extends a belt which surrounds it on all sides, and in which our whole system of colors is classed under two heads, exactly as in the case of the red-blind. We have here, as in the last case, but two colors, yellow and blue. In other words, we are completely red-blind in this intermediary zone; beyond this, there is a peripheral belt, in which we are totally color-blind. These are matters unquestionably of great theoretic value, but it must be acknowledged they are also of great practical importance. Although we have adopted the Young-Helmholtz theory, we must admit that the different kinds of perceptive elements of colors have a different local division upon the retina; and this is why we may speak of the topography of the chromatic sense. The fact is explained in this way: in the retina of the normal eye, there are simultaneously three kinds of elements in the central part, corresponding to the central region of the visual field. Toward the periphery, beginning at the central fossa, the elements become more and more rare, but in unequal proportions, so that the perceptive organs of red cease first, and this at a limit corresponding to that of the central region. In a belt which answers to the intermediate zone, or the belt of the red-blind, there remains in consequence but the perceptive elements of *green* and *violet*. At the limit near the periphery of the retina, corresponding to that of the peripheral zone of the visual field, or region of absolute color-blindness, the perceptive elements of green cease also, so that there only remains in this last zone the perceptive elements of violet. We have been especially led to this last conclusion by the examination of two cases of color-blindness, where the visual field was so abnormally small that the peripheral zone seemed to be effaced, and where we besides recognized the characteristic features of violet-blindness. This experiment, which perfectly harmonized with the theory, showed us the relation of complete red-blindness to the normal chromatic sense. Red-blindness is distinguished from the normal sight in this, that the normal central field is wanting, but is replaced by a mean corresponding at the same time to the central field and to the intermediary zone of the normal sight. We have also succeeded, owing to the peripheral investigation of the colored visual field, in verifying in a great number of cases the continuous series of forms of transition which we have classified as one kind under the head of *incomplete color-blindness*, or in the instance especially occupying us here, *incomplete red-blindness*. In the same way, the other kinds of color-blindness may also, as regards the visual field, be classified according to the theory. The visual field of the green-blind is distinguished from that of the normal observer in this, that it has a peripheral field corresponding in extension both to the intermediary and peripheral zones of the normal observer. The violet-blind is distinguished on the other hand in this, that it is completely deficient in the normal peripheral zone. These two kinds of *incomplete color-blindness* are characterized by a central field diminished at every degree. With regard to the visual field we may therefore lay down this rule, that it has as many distinct zones, with reference to the perception of colors, as the chro-

matic sense has fundamental colors or different kinds of perceptive elements, and that the different degrees of incomplete color-blindness are in the inverse ratio to the dimension of the visual field. If the central field is limited to a circle of ten degrees from the fixed point, all the respective characteristics of color-blindness are usually found in it, sometimes within even a narrower range. A feeble sense of color manifests itself in a much wider central field. All the anomalies that can be discovered in an examination of the visual field might, in consequence of the method employed, be explained by a diminution of excitability as well as of the number of the elements. The intermediary zone of the normal visual field or belt of red-blindness has an especial interest, as it furnishes us with the opportunity of seeing with our own eyes as the red-blind sees, and consequently of exactly comprehending his abnormal perception.

According to the theory, we see only yellow and blue in this belt, and in consequence we admit that the red-blind not only *call* yellow and blue their principal colors, but moreover *see* them exactly as the normal observer does. This hypothesis cannot assuredly be proved, but this is not necessary, as the explanation Helmholtz has given of the designation of one of the principal colors of the red-blind is perfectly satisfactory. This circumstance, however, has given rise, amongst others, to a doubt about the Young-Helmholtz theory, and to another theory admitting four principal colors to the normal sense of colors, yellow being classed amongst them. But this is useless. It must not be forgotten that colorless light as well as colored light are subjective perceptions, and that *comparison* here performs an important part. This fact is sufficiently proved by the phenomena of contrasts, accidental colors, etc. White is not a color; it is merely a general, neutral light, and is therefore produced when one kind of element is not more excited than another, or when all the elements are equally excited.

But as the theory obliges us to admit that the excitation of the perceptive elements of green and violet may in certain cases, as in the instance of the red-blind, supply the perception of white, and not bluish green, and that in certain cases, as in that of the green-blind, the excitation of the perceptive elements of red and violet does not give purple, but white, it is in no wise contrary to the theory to admit that the excitation of the organ perceiving green gives the perception of yellow in cases where all that remains moreover of the system of colors is the complementary color of yellow, that is to say, blue. The excitation of the perceptive organ of green gives the perception of green only on the retina or on a point of the retina which also contains the organ perceiving red. But this is not the place for further developments of this theory.

2.—CLASSIFICATION OF THE DIFFERENT KINDS OF COLOR-BLINDNESS.

In the preceding we have indicated, in conformity with the theory, the different forms of a defective sense of colors to which, we think,

should be applied the name of color-blindness, and which, owing to their nature theoretically, must be considered as of different kinds. This division will be sanctioned if we consider the relations in which it stands to the method pursued for discovering them, and which is based on the Young-Helmholtz theory. It is this we are about to explain.

We classify the different kinds of color-blindness under especial heads, to be able the better to grasp the whole. We might indeed divide this blindness into congenital and acquired, but as such a division has reference alone to the mode of origin, and not to the nature of this blindness, and affects in no wise the manner of its discovery, it has no practical importance in the case now occupying our attention. Besides, our division relates, as does our entire memoir on this subject, essentially to congenital color-blindness. The division is as follows:

I. Total color-blindness (*total fargblindhet*), in which the faculty of perceiving colors is absolutely wanting, and where the visual sense consequently can only perceive the difference between darkness and light, as well as the different degrees of intensity of light.

II. Partial color-blindness (*partiel fargblindhet*), in which the faculty of certain perceptions of color, but not of all, is wanting. It is subdivided into—

1. Complete or typical color-blindness (*fullstandig* or *typisk fargblindhet*), in which one of the three fundamental sensations, one of the three perceptive organs of color in the retina, is wanting, and in which consequently the colored visual field has but two ranges. This group includes three kinds, namely:

(*a*) Red-blindness (*red blindhet*).

(*b*) Green-blindness (*grön blindhet*).

(*c*) Violet-blindness (*violett blindhet*).

2. Incomplete color-blindness (*ofullständig fargblindhet*), where one of the three kinds of elements, or perhaps all, are inferior in excitability or in numbers to those of the normal chromatic sense. Incomplete color-blindness exhibits, like the normal sense, three zones in the visual field, but is distinguished from it by an unusually small central field. This group includes the whole of a series of different forms and degrees, a part of which—the superior degrees, which might be called *incomplete red-blindness* and *incomplete green-blindness* (and *incomplete violet-blindness*)—constitutes the transitions to the corresponding kinds of complete color-blindness, and another part of which—the inferior degrees, which we call a feeble *chromatic sense*—constitutes the transition to the normal sense of colors.

We will show further on that this classification, based entirely upon the Young-Helmholtz theory, is quite practical, and conformable to experience. We know no classification which, though distinguishing accurately between the different essential forms of a defective sense of colors, draws a surer, more decided, and more practical limit between the defective sense of colors and the normal sense.

For the classification of the different forms of the defective sense of colors, regard is generally paid to the methods of investigation, and the division is governed much more by those methods than by a theory of the sense of colors. But in every case it is found that the classification latterly in use leaves room for much improvement, either because some of the forms of defective color-sense not taken into account, or, on the other hand, because even some cases of normal chromatic sense, wanting in exercise and intelligence, have been classed amongst the different kinds of defective color-sense. As an instance of the first kind, Dr. Stilling's classification should be mentioned, which is based upon the theory of the four primitive colors, complementary two by two. According to it, there could be but two kinds of color-blindness, namely: "*rothgrünblindhet*" and "*gelbblaublindheit*" (*green-red-blindness* and that of *blue-yellow*). Without allowing ourselves to criticise the theory itself here, we will simply remark, looking at it practically, that, on one side, this classification draws no distinction between the various kinds of red- and green-blindness, Dr. Stilling classing them as one, and that, on the other side, the whole series of forms classed by us under the head of incomplete color-blindness is not included in his plan.

As an example of a classification of the last kind, the one which seems universal in France, and employed by Dr. Favre and Dr. Féris, may be cited. It is reduced nearly to this: all those who give false names to the primitive colors belong to one class; those who are only mistaken in the shades, but not in the principal colors, are classed under another; and, finally, those who, after several trials, evince some hesitation in designating colors, form a third class. It is plain that this classification gives but little idea, properly speaking, of the nature of the different kinds, and that the third class must include a large number of individuals endowed with normal sight, but who have been mistaken or hesitated at the time of the test, in consequence of want of exercise.

3.—COLOR-BLINDNESS IN PRACTICAL LIFE.

Volumes might be written on this subject, if the different instances of all the peculiarities presented by color-blindness, and all the embarrassment to which they give rise, were cited. We will limit ourselves to a few facts here, closely connected with our really practical end, and over which they exert a direct influence. To avoid being prolix, we will merely remark that in alluding to color-blindness in general, without naming one especial kind or form, we usually mean the ordinary typical kinds of partial and congenital color-blindness, namely, red and green.

We must first remember that color-blindness is not a *disease* in the sense of being attended with suffering, obliging the individual to have recourse to a physician. Color-blindness, quite as well as the normal sight, is a sense of color, though of another and a more simple nature. He whom we call color-blind is not correctly speaking at all blind to

colors. He perceives, in the main, the same kind of light as the normal observer, but sees a part of it in another manner. In the system according to which he arranges his colors, he has fewer kinds than the normal observer, and this is why he is obliged to classify under the same denomination a portion of the colors classed by the normal observer under different heads. It results from this that he finds resemblances between colors or confuses others that the normal observer finds different; for instance, red and green. These confusions naturally surprise and amuse the normal observer, who readily imagines that it arises from very great ignorance of colors, or from defective training. He ordinarily supposes that there is no limit to the mistakes the color-blind might make in this respect. But such is not the case; he obeys laws quite as exact as does the normal observer; a color-blind person can no more accustom himself to seeing colors as the normal observer does than the red-blind can see colors in the same way that the green-blind does, or conversely.

This theory, which is based upon experience, explains to us how the color-blind see colors. But if we only base our ideas on the names given to colors by the color-blind, we can be easily deceived. To judge correctly of color-blindness, and the various practical questions connected with it, it is of the highest importance to distinctly observe the difference between the manner in which the color-blind person *sees* and the manner in which he *names* colors. The sensation is based upon the nature of the sense of color in the organization of the optic nerve from birth. The *name*, on the contrary, is learned; it is conventional; it depends upon exercise and habit. The names of colors are naturally the objective expression of subjective sensations; but, on the other hand, they are regulated by the system of normal sight, and cannot consequently agree with that of the color-blind. They can, nevertheless, be learned by the latter, and even applied correctly in many cases. There is connected with this fact a peculiarity of the utmost importance practically to the question in point, and one that has given rise to the most serious embarrassments and misunderstandings. This has been and is still one of the chief causes of our erroneous ideas on the subject of color-blindness existing in the masses, because it is the veil under which this defect usually conceals itself from our observation in every-day life, and under which, even to the last moment, it will succeed in escaping discovery in cases where, as frequently happens, the methods of exploration employed are indecisive or are based upon erroneous principles.

If we reflect on the condition of the color-blind, it is difficult to understand how he can avoid being detected in his daily intercourse with men endowed with normal sight. And yet experience has sufficiently controverted this idea. That which we have acquired in examining *en masse* the *personnel* of a railway, for example, where it is required night and day to give attention to colored signals, is singularly worthy of notice. We learn by it that a number of color-blind were discovered, although

their defective sense of color had never been suspected by themselves or any one else, and the majority had correctly performed their duties. Such a condition of things furnishes us with food for reflection, and it will not be uninteresting to examine some of the peculiar circumstances which explain it. All the details connected with the subject cannot be, of course, enumerated here. We will content ourselves by merely indicating the course to be followed to obtain this explanation.

Agreeably to the property of our senses to serve as sentries before the external world, we interpret the information they give us in a particular manner. In fact, we do not consider the changes that take place in our sensitive apparatus, of which alone, however, we possess any immediate perception, but refer everything immediately to the cause that has provoked it (that is to say, to the external objects), and we attribute as qualities properly belonging to them what in truth is merely a process of our own organs. If an object simply reflects certain kinds of rays of light to our eye, we preceive a certain corresponding color, red, for example. We ascribe this perception to the object itself as an attribute, and we say it *is red*. A red carpet seen by daylight is and remains red. It is red by no matter what kind of light. It is red even when behind our backs or before our eyes in the dark. We discard the sensation of red, which belongs to our optic nerve, for the *quality* of red, which we ascribe once and forever to the carpet, and by this *name* of red we supply a whole definition, which, to be complete, should be stated nearly thus: "A red carpet is a carpet which, by the ordinary light of day, reflects only ethereal waves creating, when in contact with the retina of a normal eye, the perception of red, but absorbing, *per contra*, all the other luminous waves." It is owing to this manner of imputing qualities to objects that the name *black* has been admitted amongst the names of colors, although properly speaking it would designate the quality of absorbing all light, and consequently of not at all affecting our eye. Now the tendency to employ our senses, as we have just incidentally stated, is often promoted by a school education so limited and partial that the immediate impression is referred to the external object, and the faculty of observation is suppressed to give place to descriptions and to names.

As color is an immutable quality in a variety of objects of different colors, it is not very difficult to learn their names by heart. The direct impression is not even necessary. We may hear a really blind man, even one born blind, give the exact names to colors of common objects of which he has often heard. To the color-blind this is still more easy, as he derives some assistance from his incomplete chromatic sense. On the other hand, it must be comparatively very rare to meet one color-blind, who influenced as Dalton was by individual interest carries his reflections on colors and the chromatic sense so far as to reach the point of discovering his own anomaly. Amongst the color blind discovered by us,

while directing our researches especially to this point, not a few have been painters and tailors.

But such disregard to the subject of colors is no longer permitted in occupations where colored signals are employed and where human life may depend upon the manner in which the signal is or is not understood, as on railways and at sea.

A great number of color-blind are to be found employed in almost every position on railways, without the defect in their chromatic sense being suspected by themselves or others. Nay, more, a number of them, far from being willing to acknowledge, even after the examination, the existence of such a defect, urgently demand a new trial, even six or seven, offering all kinds of pretexts to account for their repeated failures. They all agree in declaring that they have excellent sight; that they have never had the least difficulty in distinguishing signals, though they have been employed for a long time and in the most important positions, that for instance of engineer, and had never made the slightest mistake; that the engineer is never the only one whose duty it is to watch the signals. He has always near him a fireman, and in his neighborhood an assistant engineer, a greaser, etc., who come to his aid at critical moments. That must be a very rare case where all the officials are affected with color-blindness.

Looking practically at the fact mentioned and the explanation given, it might be imagined probably that color-blindness, although a subject of scientific interest, could not possess any possible practical interest. At least, it might be believed that all the stir which has been made in our country about color-blindness amongst railway employés was founded upon nothing real. Since it is proved (it may perhaps be urged) that the color-blind have long been employed on railways and the defect never remarked, without any accident or even inconvenience resulting from it, and finally since they can really learn to distinguish signals, although otherwise than by colors, their kind of blindness should not legitimately give rise to any preventive measures whatsoever. And doubtless a great many still reason in this manner.

We will not dwell here upon what experience has or has not proved with regard to this in our country. The fact is certain that color-blindness in other countries has caused numerous and serious accidents. And even though experience should not have proved it in an absolute manner, it would not be the less evident that in such cases no one has the right to await a new experience of this kind before proceeding from words to acts, inasmuch as it can be demonstrated that, in spite of the many circumstances aiding the color-blind to obey signals, all danger is not averted, and uncertainty still remains. Now, this is not difficult to prove, for neither the fact that color-blind individuals have been long employed on railways without causing accidents, or without the discovery of the defect, nor the circumstances we have cited to explain this fact, furnish the slightest ground for security.

A color-blind individual of the typical kinds cannot distinguish red from green. This is an undoubted fact, easily explained by theory and adequately proved by experience. All that he asserts about differences between these colors is founded consequently upon conjecture. But this manner of perceiving signals is attended by great uncertainty, and he who guesses correctly in this manner in a certain number of special cases must infallibly guess wrong in some cases. This is a principle which does not rest on a theory, but which has been confirmed by our experience without an exception in an examination of more than two hundred color-blind persons, and its evidence could be extended far beyond the limits to which we are confined here, or, in other words, to the majority of the cases of incomplete color-blindness.

If a small amount of soot, smoke, vapor, ice, snow, etc., adhere to the glass, the lantern shines less brightly. A lantern shines differently in clear or foggy weather, etc. All this may give rise to mistakes. But, on the other hand, the sensibility of the eye is very different according to circumstances. The nervous organ of the eye may, like every other part of the system, vary extremely in sensibility. The same light is to the sound and rested eye stronger than to the weak and tired eye, etc. But every modification of intensity of light is equivalent, to the color-blind, to a change of color. All this proves how little reliance can be placed upon the knowledge of signals acquired by the color-blind by practice.

III.—REFORMS RELATING TO COLOR-BLINDNESS.

As we have shown already, the tendency of color-blindness to conceal itself wheresoever it occurs, in all classes of society, especially in the lower, may be regarded as one of its most remarkable peculiarities. It is necessary to add still another circumstance: one whose color-blindness has been disclosed, and who is thus himself made aware of his defect, and who has been, as is so commonly the case, a subject of ridicule to his acquaintances, is generally more than ever eager to conceal his infirmity. The result of this is, in spite of all that has been written on color-blindness, this affection of the sight, far from being recognized as a fact belonging to every-day life, has been and still is considered by the public as a legend about which anything desired could be believed. The idea, at least, usually formed with regard to its frequency and practical importance, is far from corresponding with the reality. It is difficult to accustom one's self to the idea of the necessity of refusing to a number of persons admission to a career which would afford them means of subsistence, and, what is worse, to discharge from their present position those who have performed their duties in an irreproachable manner, and which have been to them and their families a legitimate source of income.

Prompted by a just regard for the good of man, it is asked whether

the difficulty in distinguishing colors experienced by certain individuals may be corrected by exercise. And if this is not possible, it is natural to conclude that more regard is due to the men than to a particular kind of signals, since the latter is not absolutely essential, and consequently may be changed if not adapted to the employés.

1.—INSTRUCTION AND EXERCISE OF THE PERSONNEL IN RECOGNIZING COLORS.

The importance of the habitual exercise of our senses generally should not be underrated. As we are born with naturally sound organs of locomotion, and yet require to be taught to walk, so it is necessary to learn to use our organs of sense; and when experience shows us that many original defects of our organs of locomotion can be remedied as well as those of our visual organs, we readily conceive the idea that this is also possible with color-blindness. If it were the case, this would be, without doubt, the most radical means possible for protecting railway lines, without the necessity of displacing a single employé.

To avoid all misunderstanding, we must dwell upon the difference that we have mentioned between the genuine *perception* of the color-blind and the *name* he gives to the color of the objects. We have already seen that a true name may often be united to a false perception, but it is evident, also, that just as the perception is anomalous, or merely uncertain, the name must also be uncertain, as it is simply a conjecture. We do not here allude to that *acquired* color-blindness which, casually occurring, might also disappear, but to congenital color-blindness, let it be understood.

We will endeavor to give some account here of what experience has furnished on this subject, and first of all we will try to discover upon what grounds it is claimed that color-blindness can be cured.

An effort has been made to derive one indication of this from the fact that amongst the numerous instances of color-blindness that have been discovered and mentioned by different writers since Huddart, there are many more amongst men than women. It is concluded from this, in the first place, that color-blindness is much more common amongst men than women, and from this statistical fact, added to the undoubted experience that women have more to do with colors from their very infancy than men, from the nature of their clothing, etc., another inference is reached, namely, that exercise assists in diminishing and counteracting color-blindness. All this may be true, but the argument fails in more than one particular. In the first place, it has not been at all proved, we think, that color-blindness is less common among women than men. The majority of the cases of color-blindness described by writers have been accidentally discovered, that is to say, without any special examination. If we observe, first of all, that these are probably the most marked cases of color-blindness, and also that they are usually not persons who have much to do with colors (as these easily conceal their defect), it will be

readily understood why the female sex has furnished so small a proportion to statistics. Again, in cases where experiments are made to discover color blindness, it is evidently much easier to find opportunities to examine men than women. For the most part, those examined are soldiers, students, agents of police, etc., it being difficult to find equal opportunities for examining women *en masse*. It is necessary to operate on a large number to obtain very satisfactory statistics. The data we possess are furnished mainly by experiments among men. This is why we venture to dispute what is usually admitted as a certain fact, that color-blindness is more common among men than women, the necessary information being so far wanting to establish such a fact. We must not overlook the testimony of Prof. H. Dor on this subject, who examined the very considerable number of 611 women at Berlin, amongst whom he found only five color-blind, or little less, therefore, than 1 per cent., or exactly 0.82 per cent. We do not desire in the least to deny the possibility that color-blindness amongst women is less common; on the contrary, we think it even probable that this may be the case.

In using the statistics of the experiments thus far made on women, it is important to observe carefully whether the method of scrutiny has been such that previous exercise has not had some effect upon the result. For if the method is founded upon the principle that those examined must be interrogated as to the names of the colored objects presented to them, and their chromatic sense judged according to the answer, it is clear that the proportion of failures will be relatively less amongst women than men, as they have much more practice. We are not certain that this may not be the explanation of the result thus far obtained.

For a number of years, Dr. Favre devoted himself to the study of color-blindness amongst railway employés, and succeeded in introducing reformatory measures on several railways in France. This circumstance, and the manner, also, in which he has treated this subject from several points of view, are more worthy of attention, since he has boldly pronounced in favor of the curability of color-blindness by exercise, and urged measures founded upon this principle. We will give his result in the author's own words:

"Out of one hundred and forty-six scholars, from seven to sixteen years of age, belonging to two schools, one hundred and eleven named the natural colors without error or hesitation: thirty-five made mistakes in different degrees: twelve made serious mistakes with regard to several colors; the errors of the others were with regard to orange, blue, or violet: some were mistaken about all these three colors, others about two, and some only about violet. These thirty-five children were subjected by their instructors to repeated methodical exercises according to the directions I had given them. One of the teachers cured all his defective pupils; the duration of the treatment varying from two weeks to six months. The other teacher had on the 2d of April of this year only two patients out of eleven uncured."

In an additional note, he adds: "This account of the treatment of color-blindness must be brief on account of the object for which it is intended; but it may be necessary to set forth in a few words the process in use in schools. I have simplified it as much as possible. The chief point was to have the colors corresponding with those of the solar spectrum, that is, those generally designated by the names of *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*. The scale of colored wools that I presented in large quantities to managers and agents of railways, to my colleagues, to several teachers, male and female, and to individuals under treatment, was thus arranged: five packages were composed of three shades each—three shades of *red;* three of *yellow*, including *orange;* three of *green;* three of *blue*, including *indigo;* three of *violet;* and besides one package of white and one of black wool. The children are summoned one after the other, and separately interrogated. The examination of those who are without this defect, and are well trained, is soon made. Those who hesitate or trip should be treated with great indulgence, and set straight, if I may so express it, and if their errors are not easily corrected, their answers are accurately noted down. The master then, in another lesson, shows and names the colors to the children, and makes them *repeat with him*. It is important not to make the inexpert pupil an object of ridicule or even of attention to his companions. The lesson should be repeated every three or four days until he is quite certain that the idea of colors is well established. The training is completed by making them name the color of the various objects within reach of the master; flowers, fabrics, geographical maps, etc. Our pupils will not be able to distinguish the 14,420 tints established by M. Chevreul, but they will have acquired the indispensable minimum: they will know the *a*, *b*, *c*, of the science of colors."

What we have just quoted cannot essentially change the view we have adopted and described in the preceding pages. To demonstrate the curability of color-blindness, it is indispensable to prove, first, that the treatment is applied to those whose deficiency has been duly established, and, in the second place, that these same at the end of the treatment have a normal chromatic sense, or at least are not color-blind.

Dr. Favre's pamphlet does not furnish us on these points with sufficient evidence. We cannot, from our point of view, have much confidence in the method of investigation employed by Dr. Favre. It is not only possible, but even extremely probable, that ignorance and a want of practice might pass for color-blindness, and especially as the examination is that of children. That there were among the individuals under Dr. Favre's treatment some cases of genuine color-blindness would appear from the fact that two children, a year after beginning the training, had not succeeded in learning the task imposed, which nevertheless does not seem to present insurmountable difficulties, even in instances of persons really color-blind.

In brief, without attempting to deny the curability of color-blindness

theoretically or practically, we maintain that not one positive proof of it has so far been produced.

It is a significant fact that individuals who have themselves discovered their own chromatic blindness, and have been very much interested in it, having reflected and experimented, and consequently exercised themselves much in colors, have nevertheless retained their anomalous perception, such as it was in the beginning, for many years, indeed, as long as they lived. Such was the case with Harris, who himself discovered his defect at the age of four years, and studied it with much interest, but never succeeded in correcting it. Milne was found by Wilson to be as color-blind at Edinburgh in 1854 as he was thirty years before, when Combe examined him. Such was also the case with Professor N——, examined twenty years before by Sir David Brewster. But such was especially Dalton's case, who has thrown much light upon the subject. No one will deny that if exercise in colors can cure chromatic blindness, Dalton would have been cured, and yet it must be acknowledged that at the meeting of the British Association at Oxford in 1832 he then compared a scarlet red to the leaves of trees, proving him to be as color blind as in 1792, the date of the discovery of his color-blindness, and as far as his friends could observe he continued so to the end of his life (1844).

The history of science tells us of cases of persons completely blind who can easily and correctly distinguish wool of different colors by means of other senses, smell, taste, or touch. The power of touch in this case deserves especial attention, as it is exactly adapted to the kind of qualities now interesting us. The close connection between touch and sight in determining whether an object is smooth, rough, etc., is well known. The assistance which these two senses render each other in a general appreciation of everything in space is not less well known. These are the very qualities, beyond any doubt, that the color-blind call to their aid to supply the place of colors. This is why many color-blind are seen placing the samples of wool in different lights, bringing them quite close to the eye and in different angles to the visual axis. But we have heard many color-blind, who knew the difference between red and green, or purple and green, frankly acknowledge that they only recognized them because one colored wool was coarser, harsher, or rougher than the other. Consequently it is not the color, that is, the quality of the reflected light, but the coloring matter and its peculiar effects upon the wool, which were to them the distinguishing features. As the result of our investigation we can state that exercise is certainly not without value, but is more useful in other respects than in curing color-blindness, or in removing the causes of the mistakes made by the color-blind with regard to the colors of signals. We maintain, therefore, that not one case has been sufficiently established to prove that a genuine case of color-blindness has ever been cured by exercise.

But it in no wise follows, we repeat, that we deny the possibility of

improvement in cases where the corresponding organs are not wanting, but are simply deficient in sensibility. Moreover, we are very much indebted to Dr. Favre for having interested himself in the question of the treatment of congenital color-blindness, and also for having undertaken the work of applying this treatment. If this idea is generally admitted, it will, without any doubt, produce excellent fruits, among others that of introducing examinations into schools, so that color-blindness will be discovered in time to be cured, if that is really possible, or if not, that its subjects may be enabled to choose a career in which their infirmity will not be attended by inconvenience or danger. This is, moreover, the only means by which we can reach a perfectly decisive answer to the extremely important question, whether or to what degree color-blindness may be improved or cured. But it is also evident that the more important the answer to this question, practically, the more does its solution require critical methods and rigid investigation and control in order that when the answer is once obtained no doubt may be cast upon its accuracy.

On the other hand, we oppose in the most positive manner every measure relating to railway officials, sailors, etc., founded upon the idea of the curability of color-blindness, until this question has been perfectly established by an affirmative answer. It is evident that otherwise not only is the danger of employing the color-blind on railways, etc., not diminished, but also that the introduction of a radical reform in this matter is impeded. When Dr. Favre requests that the *personnel* on railways and in the navy, etc., be exercised in distinguishing colors, this demand, favorably received, can only lead to the admission of the color-blind to the positions in question; and then under the assurance that their congenital defect may be cured, they are watched over until they acquire the necessary amount of training. According to our opinion, such a measure is positively dangerous, because it merely lulls the authorities with the belief that the color-blind can cause no accident, while in reality their defect is exactly where it was before, and, owing to the exercise, has only become more difficult to detect, if for this purpose a defective method is adopted. From this point of view it is apparent that exercise, far from removing the danger, only increases it. It may be answered indeed that, owing to exercise, the color-blind will less frequently confound the signals than they will without exercise, and this we willingly grant. But, on the other side, it is evident there should be no question here of an alleviation, but of a radical correction. The danger of employing the color-blind on railways or at sea once well established, it is necessary, it seems to us, to take measures for completely removing the danger, if possible. If comparative security can satisfy, we already have it, either from the fact that all the officials cannot be color-blind, or that the majority of such do not usually cause accidents. But it is precisely the desire to save the communications from this state of uncertainty that has inspired us with the idea of taking measures against it, and we believe that we have proved by what we have said that

any reform that can be introduced at present in this matter should be established just as if it were already decisively proved that color-blindness is incurable. It is therefore this hypothesis that we intend to apply in what follows.

2.—MODIFICATION OF THE SIGNAL SYSTEM.

(*a*) *Other colors for signals.*—If congenital color-blindness is incurable, or at least if we know no actual remedy for it, it is necessary to devise some other method (while retaining the color-blind in the employment of railways) of guaranteeing the communications against any mistakes they might commit with regard to signals. It is seen by what precedes that these errors can and must occur in the use of the signal colors generally adopted, *red*, *green* (and *yellow*). This choice seems therefore unfortunate. Wilson is of the same opinion. When red and green color-blindness are the kinds of complete or typical partial blindness which are most generally seen, it would seem that the difficulty might be considerably diminished, if, in place of using the actual colors, those should be selected best suited to these kinds of color-blindness, although they might not suit the third kind of typical partial color-blindness or violet-blindness, which, according to the experience acquired up to the present time, is much more uncommon.

Undoubtedly, the principle we have endeavored to establish would not be radically enforced, but the practical result at least would be comparatively nearly accomplished. As the color-blind has but two principal colors, or two classes to which he can refer all the colors, it is evident that to select two colors that he can recognize and distinguish without the least hesitation, it would be necessary to select one from each class. In this way, it is always possible to bear in mind that each kind of color-blindness will always be able to find two colors distinctly defined, but not more than two. It is therefore necessary first to ask how far two colors for signals could satisfy the demands of railways and the navy. As regards railways, it is claimed, and it may be conceded, that, in case of necessity, and perhaps without too great inconvenience, two colors might be made to answer. It is certain that three colors are a great improvement upon two. Let us admit, however, that two colors would answer, and that it were desired to sacrifice the advantage of three colors for another advantage, namely, that of retaining in the service of railways the color blind, there will still remain the necessity of making a good selection of these two colors. This is more easily said than done. The choice must be so made that one color may be selected from each of the two groups in which all the colors are classed according to the system for the color-blind. Now, it is found, as we have already seen in the instances of the principal colors of the red and green blind, that, amongst the seven colors of the rainbow perceptible to the normal observer, four, namely, red, orange, yellow, and green, belong to one class, and three, especially blue, indigo, and violet, to the second. Consequently, one of the colors

must be red, orange, yellow, or green, and the other blue, indigo, or violet. It should very naturally be our object to give the preference in the selection to the colors which most strongly affect the eye at the time of the comparison. Now, the most intense colors of the spectrum, that is to say, the most vivid colors which enter into the white light of the sun, are yellow and blue, one of each of the two groups. We then select them, the more willingly, that the light of the lantern is, without any preparation, and to a very high degree, yellow, though it is not homogeneous. But we are far from being so fortunate with regard to blue. We here encounter a difficulty, on the contrary, which induces us to doubt whether a change of colors will accomplish the desired end.

On all colored surfaces—flags, paintings, semaphores, etc.—employed by railways to reflect during the day the sunlight or daylight, the proposed colors answer perfectly without any doubt, and, in all probability, no color-blind individual of the kinds specified would nominally make mistakes of judgment. But the night-signals are quite another matter, and are by far more important for many reasons. This is therefore why we prefer to attach here so much importance to them, as during the day a multitude of different circumstances might give warning of danger, while during the night the colored light is the only signal which indicates it.

The colored lights used for night-signals are made, as all know, by placing colored glass before the flame of a lantern. The use of Bengal lights as regular signals could scarcely be introduced into practice. Now, a colored glass produces a colored light, because, of all the kinds of light radiated from the flame, but one kind (or, at least, mainly one kind) is allowed to escape, while all the others, or a greater part of the others, are absorbed by the glass. Thus, blue glass, according to its thickness or degree of coloring, absorbs all the other kinds of light emitted by the flame of the lantern, allowing only the blue rays to escape. But, unfortunately, as is well known by direct experience, the flame of the lantern emits comparatively but a small amount of blue light when rape-seed oil and photogene, or generally any of our ordinary sources of artificial light, are employed; and this is why all appear yellow or red when compared with the light of day. Under such circumstances, blue glass can naturally transmit only a small amount of blue light; and the light of a blue lantern must consequently always be very feebly luminous.

What we have just said of blue applies equally to indigo and violet. The proposed changes of the colors of signals furnishes, therefore, but two colors in place of three; and then one is a very feeble light, so that it is difficult to see it far off so long as it is sufficiently colored. This state of things scarcely holds out much inducement to introduce a reform of this nature. And it seems the more dangerous that this change of colors in the signals would cause those with normal sight amongst the *personnel* to run the same risk that the really color-blind do; I mean that

they would be forced to distinguish and judge the night-signals alone by the intensity of the light.

The result of all that we have just said is, it seems to us, that the proposed change of the signal colors is not very practical, and such would be the case with any other choice of two colors. It must at least be conceded that the new signal colors would be to every normal observer worse than those now in use with us, as with nearly all nations; in brief, if they were adopted, it would diminish the public safety. We must add that, by adopting them, the principle we have explained is not taken into consideration, according to which it is necessary to use a system of signals adapted to all kinds of color-blindness, since the violet-blind are not able to distinguish between yellow and blue. The proposed change should therefore be rejected, it seems to us, on every practical consideration.

(*b*) *Colorless light and darkness, black and white.*—It has been seen that it is impossible to hope for colored signals suiting every one, color-blind or not; it becomes necessary, therefore, to try to devise a plan for establishing a system of signals independent of colors, and based upon the introduction of a colorless light of different degrees of intensity. While there is nothing more sensible to our sight than the relative intensity of two lights placed side by side (when the absolute intensity does not exceed certain limits), in the present case the only comparison involved is made from memory, so to speak, which is equivalent almost to an appreciation of the absolute intensity of light. We are so far from being able to judge of this, that, in spite of a deeply felt need and constant efforts, science even has not succeeded in discovering suitable measures to apply to it.

It is, however, necessary to acknowledge here that a system of signals based only on two extremes of intensity of light, namely, on light and darkness, white and black, ought to suit the normal observer as well as the color-blind. Moreover, such a system ought to satisfy all exigencies, provided it is practically applied, and that two signals only are sufficient. A white and black flag, etc., would fully suffice during the day; but such would unfortunately not be the case at night, for a black light is a contradiction of terms, and it would be necessary, consequently, according to this system for the night, when signals are of the greatest importance, to be limited not to three, but to one signal only, unless the absence of all signals could be considered as one. Here it might be well asked, whether the better system is not that which is based on the alternations of darkness and light, that is, movable signals or eclipsed signal-lights. As far as we know, no system has yet been discovered, based upon the principles alluded to above, which could advantageously take the place of the one actually in use.

(*c*) *Form, movement, number.*—If we do not succeed in finding a suitable system of signals, based on the differences of the quality and quantity of light, there remains but to appeal to some arrangement in space,

if absolutely limited to the visual sense. Many different ways suggest themselves of varying the signals by form and arrangement in space: large brilliant surfaces arranged in different forms; several small lights grouped in different positions with reference to each other; lights simply disposed, but differing in value as signals according to their number, or else illuminated figures of simple colors, and produced by different movements, and so on. A practical difficulty seems to be connected with such a system; the signals, require the illuminated surfaces to be large enough, or placed at distances considerable enough between the luminous points, to appear distinctly afar off; now the larger such a figure, having the outlines marked with luminous points, the greater the risk that a portion of it be hidden by other objects intervening between it and the eye. These two inconveniences must be apparent, particularly if these surfaces and illuminated figures have to be placed at every point where colored lanterns are found, as for example on locomotives and cars.

If the system of signals were based upon form, and all persons discharged from the service of railways who, in consequence of an imperfection of vision, could not clearly and decidedly distinguish these signals at a distance, the proportion of such would be larger than that of the color-blind. To form an idea of the different capacities of the normal eye in the various senses just mentioned, we will recommend a very simple experiment. Take something, colored paper, for example; make some plain figures, such as letters, one of which must be attached vertically to a large black or white surface. To prevent any distraction from subjective influences, let some one else select and attach this letter, while the observer stands at such a distance that even with the eye directed toward it but a single object can be seen. If the letters are small, it is not necessary that the distance should be very great. Then if the symbol be slowly approached, with the eye fixed on the colored surface, the following observations in the order in which the different impressions succeed each other will be made. When the letter is first perceived, neither form nor color can be distinguished; nothing is seen but a point or patch darker than the background, if that be white, or lighter, if it be black. The first attribute remarked, as the distance diminishes, is its color. When the color is very distinct, it is necessary to approach considerably nearer before the form is perceptible, that is to say, before this letter can be read, and its name given. This simple experiment clearly shows that the eye, as far as it is possible to compare its capacities in different directions, is first sensible to the relative intensity of light, then to color, and finally to form. It would be necessary, of course, to consider various circumstances relative to the choice of color, form, etc., if the experiment should be made with exactness to serve as a basis for a scientific demonstration. It would appear therefore that a system of signals based on the power of distinguishing light from darkness is less suitable than the one now in use; not only because this is based upon

the principle of the difference in the quality of light, that is to say, on color, but because, in the application, the very colors have been chosen which in practice are the best adapted to the object in view. Experience also seems to have decided in favor of this system, since in spite of the substitutes proposed with a view to retain the color-blind, it has up to the present time maintained its ascendency, so to speak, throughout the entire world.

3.—DISMISSAL OF THE COLOR-BLIND.

It now remains to solve the question of what reform is preferable. Is it necessary, in order to facilitate the free admission of all classes of color blind to the service of railways, to change a system of signals recognized as the best and generally accepted, or, continuing the system, to discard the incompetent? It is manifest, from what we have just said, which measure is most conducive to the safety of railway lines. All depends upon knowing whether, from solicitude for the color-blind, any measures tending to diminish systematically or on principle this security should be countenanced. We are fortunately accustomed to accepting the maxim that private interest must yield to the general welfare. The proportion of color-blindness in the population of a country is relatively very small. It is true that railway employés are not made for signals, but the signals for them; yet it is no less certain that in this matter the first consideration must be the public good, and not a personal advantage. It is, without doubt, very praiseworthy to desire that any one afflicted with a congenital defect, for which he is not responsible, should not be debarred from entering every career open to those more favored by nature. But this case is not peculiar, for there are many other careers to which every one has not access for want of the natural ability requisite for the efficient discharge of the duty; and there are numbers of persons who, in consequence of some natural defect, cannot be admitted into even the most common occupations. We will, therefore, maintain the position that, as long as the existing system of signals used on railways is considered in almost all respects the best known, it is indispensable that no one incapable of rapidly and accurately distinguishing red, green, and yellow should be allowed to fill any position on railways involving any connection with colored signals.

IV.—GENERAL PRINCIPLES AND PLAN OF CONTROL OF THE CHROMATIC SENSE.

It is, of course, to the interest of railways not to take into their service persons having any degree of defect in their chromatic sense. It must be acknowledged that in several posts on railways, the observation of signals is not considered an indispensable requisite; but as it is, at least, unfortunate to have an employé who *can* not, in case of need, attend to the signals, we consider this reason alone as quite sufficient. For no one,

and still less a color-blind individual, could be regarded as born especially for a railway employé. Numerous other vocations are open to the color-blind, although they might, on account of this defect, run the risk of finding themselves excluded from many occupations where color-blindness is much less injurious than to railways. Hence, we conclude that the decision to be adopted in this matter must be comparatively very stringent, that is to say, *that a relatively slight defect of the chromatic sense must suffice to prohibit admission to the service of railways.*

The question is quite a different one with respect to those already employed on railways, and other points must be weighed. It may be necessary, perhaps, to remove them from a position which suits them, and where they have earned a livelihood, and performed their duties in the most irreproachable and decorous manner. *It is just, therefore, that the least severe principles be applied, and their personal interests as much as possible considered without violating the requirements for the safety of the line.*

In this case, no one should be dismissed without plausible reasons, and when any such exist, the employés to be discharged should be treated with as much consideration as possible, and receive a legitimate compensation for their loss by the offer of another place or a pension.

In order to secure an intelligent supervision and control, each employé should submit to a rigorous examination of the chromatic sense, that there might not be the slightest doubt as to the nature of its capacity. To be able to attain this end in a perfectly certain and at the same time practical manner, while creating as few difficulties as possible, is without doubt the most difficult part of the reform to execute. It is admitted as a fact that color-blindness may manifest itself in persons formerly endowed with a perfectly normal chromatic sense. This is what is called acquired or pathological color-blindness, only lately known, and far from being as much studied as the congenital defect. It would be perhaps more suitable for our practical purpose to divide pathological color-blindness into two classes, one of which might be called *general* or *regular*, and the other *local* or *irregular*. We will understand, by the first term, that kind of pathological blindness due to general causes, and usually concentrically disposed about the yellow spot; and, by the second, that which is produced by local causes, and appears eccentrically placed in the visual field, or having its center in the blind spot. This last class should not belong to the subdivision now occupying us, principally because it rarely appears in such a degree as to be able to occasion any danger to railways. There is no doubt but that this acquired blindness really exists. Dr. Favre and several other writers have especially devoted themselves to this form of color-blindness amongst railway employés; they have pointed out several causes to which it is due, and proposed measures for discovering it. It is of the highest importance here, it seems to us, that perfectly certain methods of investigation should be employed. Dr. Stilling justly remarks that the great frequency of congenital color-blindness constitutes one of the principal difficulties encountered in obtaining an

accurate knowledge of pathological blindness. It is also plain that in cases where pathological color-blindness might be confounded with congenital blindness, there is no means of arriving at a knowledge of its true nature, unless in an individual who, after a rigid examination previously made by a trustworthy method, had been found to possess a normal sense of vision. But it can scarcely be admitted that there have been any such cases amongst those hitherto cited. But there is no better way of definitely solving this question than by systematically organizing observations and repeated examinations on railways where all the *personnel* have been previously examined. On this point, among many others, the interests of science and those of the public go hand in hand.

Within the last few years sufficiently positive information has been gathered to be able to form a fixed plan for enlarging these examinations. Dr. Favre tells us—according to his experience and that of several of his colleagues—that common causes of color-blindness are contusions, serious illnesses, such as typhoid fever, etc., and the abuse of strong liquors.

After every accident by rail or at sea, from collision, etc., where mistakes in distinguishing colors have been the principal or secondary causes, not only the *personnel* present at the time of the accident, but also all who have to give testimony about the signals, should be subjected to a rigorous examination. The necessity of this measure must be evident from what has been said before. It is absurd to condemn any one because some one who is blind says he has *seen* him violate the law, or to exculpate him because the blind person has *seen* him fulfill this law. To solve the problems involved, it is necessary to make periodic examinations, 1st, of every one who has a chromatic sense already acknowledged as defective; 2d, of all who have had contusions, etc.; and, 3d, of the whole *personnel*, to discover any color-blindness that may have arisen without apparent cause. The result of all that has been said is, that it is absolutely necessary that the directors and principals should be perfectly familiar with the nature of the chromatic sense of each one of their subordinates.

V.—SHORT CRITICISM OF THE USUAL METHODS OF INVESTIGATION.

Our exposition of color-blindness has shown, we hope, that, in spite of its wide divergence from the normal chromatic sense, it is not so easily discovered as one might imagine: quite the contrary. Just in proportion to the increase of our knowledge of color-blindness and the peculiarities of its subjects have we been led to establish different methods for its discovery. Several already exist, which differ from each other in the very principle upon which they rest or in the application of this principle.

Supposing the usual signal-lights be presented, one after the other,

to the person examined, he being required to name the colors or their value as signals, his chromatic sense could not be judged by his answer. For we have seen, on one side, that the color-blind *can* guess correctly in such cases, and, on the other hand, it is scarcely necessary to say that the normal observer might make a mistake in the name, either from negligence, through inattention, or simply by a *lapsus linguæ*. How many times, then, must the trial be repeated to secure positive results? How often must the individual make mistakes to be considered color-blind? How many times may he make them without being considered color-blind? Evidently there is no categorical answer to these questions. We are therefore authorized to conclude that the examination by means of railway-lanterns, for discovering color-blindness, must be considered for several essential reasons as an impracticable method, and consequently to be rejected. The use of flags, for the same purpose, is still worse. A general principle, applying to every examination of the chromatic sense, is that such examination should not at first endeavor to trace the connection of the chromatic sense with signals of any kind whatsoever, but have in view only the discovery as to whether the subject *is or is not color-blind*, or whether the *chromatic sense is defective or normal*. While none of the various methods proposed can be condemned as absolutely barren, there are several which, used alone, never give positive results, or give them only in a limited number of cases, or else cause so great a loss of time, and are so inconvenient, that they ought to be rejected from this consideration alone. We class amongst these methods all those which, as in the examination by means of the lantern, have a tendency, in principle, to place before the one to be examined different colors or colored objects to be named by him. The real question is not to discover the degree of skill comparatively attained by each one in correctly naming the colors, but the manner in which he sees them, or, in other words, the nature of his chromatic sense. Any method fulfilling this requirement must, in principle, be based upon the *comparison* between different colors, and an investigation into the causes of the confusion of the color-blind about several of them.

An example will more clearly illustrate our idea and show its importance. Let us take a green-blind individual; we know by experience that he confuses or finds a perfect resemblance between the shades of three colors very different to the normal eye. I allude to purple, green, and gray. The reason of this is very simple according to the theory; the green-blind is void of the organ for perceiving green. Purple, green, and gray are, in reality, the same color to the eye of the green-blind, but he has heard three names given to these colors under different circumstances. The result of this will be that he will in his turn designate this color sometimes by one and sometimes by another of these names, or else he will only use one, especially the one he first remarked or heard most frequently applied to this color. If the subject use all three names, he will apply them correctly in some instances and incorrectly in others.

But if he employ a single name, it might in a consequent manner be, according to the case, *purple* (improperly called red), *green*, or *gray*. Supposing that he uses "green," according to the denominating method, his chromatic sense will be judged as imperfect for *purple* and for *gray*, but as correct for *green*.

From our point of view, therefore, Dr. Favre's method does not seem satisfactory. Besides, not appearing to us certain, and not supplying us with any basis for a useful classification, it requires more time than is expedient: nevertheless, this principle seems usually applied in France and England.

Dr. Stillings's method is also founded upon the designation of colors, and, if for no other reason, it should, we think, be condemned. This method is based upon the principle of colored shadows. Before a brilliant light in a dark room a colored glass is held, so that the light, passing through the glass, and in consequence colored by absorption, strikes a white surface, a sheet of paper for instance, at right angles. In the neighborhood of this sheet, and between it and the glass, a slender and opaque object, a pencil, say, is held in such a manner that its shadow distinctly falls upon the paper. This shadow then seems tinted with the complementary color of the glass, that is to say, it shows the different shades of purple or red if the glass is green; green or blue-green if the glass is red, etc., in accordance with the Young-Helmholtz theory. According to Dr. Stilling, the color-blind will be recognized by the fact that the shadow in question appears to him uncolored, black or gray, while to the normal observer it assumes the contrasted color, and the diagnosis is established according to the *names* applied to the colors of the shadows by the color-blind. It must be evident that his method deserves very little confidence, and that it simply depends upon a chance, whether after such a proof a normal observer may not be declared color-blind. Besides, as the judgment is based upon the name given to the colored shadow by the subject examined, it may readily happen also that a color-blind person may be declared to have normal sight, if, as is often the case, he guess the true name of the color. Briefly, then, this method is not sure under this form. This judgment is not founded merely upon theoretic reasons, but also upon a large number of direct experiments, and is also confirmed by the examples cited by Dr. Stilling himself.

It does not, however, follow that colored shadows may not be used in the examination of the chromatic sense, if so arranged that the examiner can perfectly regulate the light according to his pleasure. According to my method, with mirrors and two lights, a *comparison* between two colors may be established. The green-blind here finds, as elsewhere, a resemblance between a certain shade of green and purple, etc. As by this method the intensity of the light may be exactly regulated, the feeble perception may also be relatively determined. The experiment we have made about this declares in favor of the Young-Helmholtz

theory, but it has besides convinced us that the colored shadows are not suitable for the discovery in the first instance of color-blindness. This is the same case with Ragona Scina's method of representing complementary colors; and also that of Rose, which, practically, strongly resembles the preceding.

After having named the processes which, according to our convictions, are not suitable for the end in view, we must mention two other methods which thoroughly supply us with the information wanted. One is due to Seebeck; the other to Maxwell. They are both founded on the *comparison* of colors, and do not assume either any knowledge or any use of the names of colors, which is, we think, an essential advantage.

Maxwell's method consists in representing two colors on a rotatory disk, to be compared by the person under examination, the tints, degree of "saturation," and intensity of light of which may be changed at will. They can be modified, until, to the color-blind, they attain an absolute resemblance. The chromatic sense is then judged by its dissimilarity to that of the normal eye. It is in this that the force and accuracy of the method consist. It shows us with certainty how the subject sees the colors as compared with each other. The Young-Helmholtz theory is confirmed by Maxwell's method, as this shows us that, by the aid of only two primitive colors, we can exhaust the whole chromatic scale of the color-blind.

Seebeck's method consists in making the individual to be examined classify a number of colored objects according to their reciprocal resemblance or dissimilarity. In this way, we have at once a complete picture of the person's chromatic sense. We learn what colors he distinguishes and which he confounds. By this method, also, we can know how he sees colors in their relations to each other. But, although these two methods are *perfectly reliable*, they are not entirely suitable for a practical purpose, because they *require much time* and are very *inconvenient*,—that of Maxwell for the examiner and that of Seebeck for the examined. He who has examined a large number of color-blind by Maxwell's method knows only too well how much time this investigation consumes, in however incomplete a manner it is made. This arises from the extreme affectation of precision by the color-blind. It is not difficult for one with normal sight to point out two similar colors on the rotatory disk, because the essential point is the resemblance in the tint of the color. But the color-blind person who cannot perceive this tint requires a complete resemblance in the intensity of light or in the degree of "saturation," and in this lies the difficulty. His appreciation often depends upon the addition of a minimum of white or black, which is to him of the greatest importance, although the normal observer cannot perceive any difference. We may add that the method is very fatiguing and inconvenient to the examiner, on account of the continual changes made in the colors, and the incessant work that the rotation of the

apparatus necessitates. Finally, if we state that the apparatus is somewhat expensive, and is comparatively difficult to transport, it will suffice, it seems to us, to condemn its use as a method of the first order when it is required to make the examination on a multitude.

The method of Seebeck causes much loss of time by obliging those examined to classify a large number of colored objects. This is not an easy task for them. It not only progresses very slowly, requiring perhaps an hour, but costs much trouble and evident effort. One may obtain a tolerably clear idea of this by attempting to do the same work with the use of blue-green eyeglasses. The colors are then seen and classified very nearly as they are by the red-blind, and almost the same difficulty is experienced. Seebeck's method, however, is superior to Maxwell's in this, that it requires the subject to make an active use of his chromatic sense, while the other allows him to remain passive, and merely announce his decision. Both methods, however, require too much time to be employed with advantage for the purpose in question. But they are the best methods known to us at present.

The *perimetric exploration* with Förster's apparatus may be excellent in more than one case for examining those before examined, but it is not advisable alone and as a primitive method. It is even inapplicable to some persons; it entails much loss of time, requires much exertion on the part of the one examined, and requires an expensive instrument, which is besides very inconvenient for transportation.

It may be very interesting scientifically to use the *spectrum* for examining the color-blind; but this method is not very appropriate for practical purposes; it requires costly apparatus, and different arrangements, which render it more or less long and inconvenient. It does not enter into our plan to give an account here of all the known methods that may be used in the first inspection, or when desired to establish a test for examination. We shall limit ourselves to the examples cited, and to explain in a special chapter the method we have ourselves used, and which of all tried seems to us best adapted to the purpose.

VI.—NEW PRACTICAL METHOD FOR DISCOVERING AND DETERMINING DEFECTS OF THE CHROMATIC SENSE.

The method we are going to describe here has been employed in all the examinations of the chromatic sense of the different classes of the population which have been made in Sweden.

1.—A SHORT SKETCH OF THE GENERAL PRINCIPLES OF THE METHOD.

Theoretically, our method most resembles those of Seebeck and Maxwell, as it is based upon a *comparison* between different colors. It therefore first seeks to discover the chromatic *perception* of the subject, disregarding the *names* he gives to the colors, as generally it is not necessary he should designate the names. Our method resembles Seebeck's

most in this, that it does not require a special apparatus for preparing the necessary tints for the examination; it assumes there will be a supply of objects of different colors provided in advance. It agrees again with this method in not allowing, as Maxwell's does, the person examined to remain passive, and simply give his opinion of the resemblance or dissimilarity of the shades indicated, but requires him to discriminate and select the shades, and in consequence reveal by an act the nature of his chromatic sense. But practically our method differs essentially from Seebeck's. His certainly gives, in a certain sense, more complete results than ours by requiring the subject to thoroughly classify, in accordance with their reciprocal resemblances and dissimilarities, the various differently colored objects placed before him. A complete table of his whole system of colors is the result of this. Our method, on the contrary, requires the person examined to select, amongst a large number of variously colored objects, those alone which resemble the sample shown him by the examiner. The difference is evident. Seebeck's method is, without any doubt, preferable when the nature of the color-blindness in the aggregate is to be considered; that is, so long as this is yet unknown. His method then gives a more complete idea than ours of the nature of the color-blindness. But for our actual purpose, the main question is to discover a defect, with the entire nature of which we are acquainted in advance. Our practical mission then is evidently to discover, if possible, some certain sign which will enable us to accomplish this end by the shortest possible route. If a single proof which would detect the color-blind as certainly as if he revealed to us his entire system of colors were discovered, this would undoubtedly be the method preferred to any other, as it would accomplish the object much more quickly and easily. This is the case with our method. We are far from denying, in general, the value of a thorough examination, but we will say that it *may* sometimes be superfluous. Its practical advantage will not be very great, if at the cost of a great loss of time, and it may even be prejudicial, if, under a multitude of details, it conceal what is essential; in a word, prevents our "seeing the city on account of the houses." All this may be applied to Seebeck's method, when the object in view is the one of which we are in pursuit. Our method again endeavors to seize as rapidly as possible one or two essential characteristics while neglecting all the others. A single caudal feather of the peacock reveals whence it came; a single flower or fruit, the plant whence it was plucked; and the genus man is recognized if we can but see a face. It is only when the face is mutilated, the flowers, fruits, and caudal feather are defective, that in certain cases it is necessary to have recourse to other characteristics. Our method rests upon these principles; it also offers the same security as Seebeck's. But, as regards the time necessary to accomplish the examination, it bears nearly the same relation to that of the learned German, that a minute does to an hour. This may seem a very trifling matter at the first glance, but is in reality of immense practical importance

when a multitude of persons are to be successively examined. A simple calculation shows us in fact that an examination requiring one day by our method would require two months by Seebeck's.

It is but just to acknowledge that it was only by weighing the results obtained by Seebeck's method and following the Young-Helmholtz theory, as well as the principles we have indicated as indispensable to a practical method, that we have succeeded in formulating our own method, such as we shall explain it in what follows. We also will remark that it is very simple and easily mastered: but we think this is likewise often the case with all that is useful and practical, and that simplicity offers great advantages. We prefer this method because it seems to us more than any other to fulfill the conditions we have pointed out as necessary to a practical method, namely, certainty, rapidity, and convenience. The only inconvenience of any moment besides those it has in common with a greater part of the others is that it requires daylight. It *can* undoubtedly be used by artificial light (electrical and calcium lights, and certain arrangements of lamp-lights with blue glass), but this causes much loss of time.

After this rapid sketch of the general principles of the method, we will proceed to give its details, and shall not fail to mention generally the reasons why, amongst several possibilities, we have selected this or that process.

2.—THE MATERIAL AND ITS ARRANGEMENT.

Our method demands neither costly apparatus nor a special place for the examination. The only necessary elements are a number of variously colored objects. It consists in taking one from a number of objects promiscuously thrown together, and asking the person examined to select from amongst them all the others corresponding with the first in color. With regard to the colored objects, it of course matters little in principle what their nature is, as, in the main, the method never changes, no matter what the kind selected. But, practically, the choice is by no means a matter of indifference. Among the ordinary objects suggested, and also used for the purpose, are pieces of colored paper, glass, or silk, or Berlin wool, etc., the last of which seems to us the best, for the following reasons: One of the chief advantages of Berlin wool is, that it can be procured in all possible colors corresponding to those of the spectrum, and each in all its shades, from the darkest to the lightest. Such selections may be found in trade, and are easily procured when and where desired. It can be used at once, and without any preparation for the examination, just as delivered from the factory. A skein of Berlin wool is equally colored, not only on one or two sides, but on all, and is easily detected in the package, even though there be but one thread of it. Berlin wool is not too strongly glaring, and is, moreover, soft and manageable, and can be handled, packed, and transported as desired, without damage, and is conveniently ready for use wherever needed.

These advantages are wanting in the other colored objects suggested for use. Colored paper or silk may be used when light or dark, dull or bright colors are wanted; but they both have these inconveniences, they must first be cut into suitable pieces, and they are troublesome to handle; moreover, they are easily concealed from view, and it is necessary to stretch them carefully on a large surface to enable them to be seen without trouble. They are often glaring; they reflect, besides their particular kinds of light, a quantity of white light, which is a prominent defect, as it misleads the color-blind, who, as we know, judge of colors by the intensity of light, that is, the quantity of light, and he consequently estimates differently the color of a brilliant surface, according to the position in which it is found with regard to the eye, etc. The paper is often colored on only one side, and this gives rise to much trouble, as it is necessary to turn the pieces from one side to the other to see them in their true colors. Finally, from being so much handled, the pieces of paper or silk soon become tumbled and faded.

Colored glass, which must be in pieces, is not suitable either, from the fact that it is difficult to procure it in sufficiently great variety. It is besides troublesome to transport, easily broken, and finally inconvenient for using, because necessary to be held against the light of day, or a luminous source, in order that the color may be seen. The advantage of being able to use them by any kind of light does not counterbalance their inconveniences.

Although these are not all the objections, the preceding will suffice to prove the advantages of Berlin wool. All this applies equally well to wafers, powders, colored solutions, spools of colored thread, pieces of wood, and porcelain, especially painted for the purpose, etc.; they can all be and have been employed, but none of these objects are, in every respect, so well suited to our purpose as Berlin wool.

A selection of Berlin wool is then made, including red, orange, yellow, yellow-green, pure green, blue-green, blue, violet, purple, pink, brown, gray, several shades of each color, and at least five gradations of each tint, from the deepest to the lightest. Green and gray, several kinds each, of pink, blue, and violet, and the pale gray shades of brown, yellow, red, and pink, must especially be well represented. The choice of the material does not belong specially to our method. In fact, Seebeck suggested the use of Berlin wool, which was employed by his advice and still is at present. To us only belongs the credit of originating the manner in which it is employed. According to our method, the examiner selects from the collection of Berlin wool in a pile on a convenient table, and lays aside a skein of the especial color desired for this examination; then he requires the one examined to select the other skeins most closely resembling the color of the sample, and to place them by its side. The chromatic sense of the individual is decided by the manner in which he performs this task. The rapidity with which this examination is made does not seem to directly correspond with the nature of the chromatic

sense, but to depend finally upon the character of the person examined. One of intelligence, with a quick, practical mind, is examined in less than a minute. In this time, in fact, a normal eye could easily find the four or five skeins of the same color as the sample, and the color-blind make a sufficient number of characteristic mistakes to thoroughly establish the diagnosis. It is clear that a method such as ours affords the opportunity in connection with the investigation of the chromatic sense of learning much of all the peculiarities relating to the use of our senses. This is why we maintain the principle that it is necessary to leave to the activity of the hands the task of revealing the nature of the sensations, and to have recourse to the tongue only for verification when there is need of more information. The combination of the action of the eye and hands, which plays in general so important a part in the training and use of the senses, is also of great consequence in this examination. An attentive examiner, especially if he have already acquired some experience, can draw important conclusions from the manner in which the other executes his task, not only and directly with regard to the nature of his chromatic sense, but generally as to his intelligence and character, and especially in some cases as to his previous training and exercise in the use of colors, and his skill in recognizing them. The examination affords us also the opportunity of making psychological observations, which contribute in a great measure in giving us a clear idea of the nature of the chromatic sense. A practiced examiner can often detect color-blindness by the first gesture, and make his diagnosis before the end of the trial. He can, according to the manner in which the task is performed, form a judgment of a feeble chromatic sense in instances which are proved correct by the final result. He also can and must see whether the result is erroneous simply on account of a misunderstanding or a want of intelligence, just as he can see whether the really color-blind succeeds, in a certain degree, from much previous exercise or a considerable amount of caution. In short, the method supplies us with all necessary information, so that by an examination made with its assistance, a defective chromatic sense, no matter of what kind or in what degree, cannot escape observation. As we have already said, the principle of our method is that the test is confined to one color.

The faculty possessed by the eye of distinguishing colors and that of defining the degrees of light and color (of "saturation") are relatively very different; but these special faculties have this in common, that they have their maximum activity in a certain intermediary region of absolute intensity of light and their minimum at the two limits of this region. Just as we experience the most difficulty in distinguishing between the shades of intensity of light by a very feeble or very strong illumination, so it is difficult for us to distinguish colors slightly or strongly luminous, or the deepest and the lightest. It is, therefore, necessary to select as a suitable color for discovering a feeble chromatic sense either the light-

est or darkest shades. The well-defined kinds and degrees of a defective chromatic sense confound only colors of mean intensity. I have selected, to determine whether the chromatic sense is or is not defective, a light green (dark green may be also used), because green, according to the theory, is the whitest of the colors of the spectrum, and consequently is most easily confused with gray. For the diagnosis of the especial kinds of partial color-blindness, I have selected purple (pink), that is, the whole group of colors in which red (orange) and violet (blue) are combined in nearly equal proportions, at least in such proportions that no one sufficiently preponderates over the others, to the normal sense, so as to give its name to the combination. This is the reason for this choice. Purple occupies a singular position amongst colors; although it is a combination, it is, we know, a color, as well "saturated" as the colors of the spectrum, and might be, from this point of view, classed with them, although it is not found in the spectrum. In fact, it has been regarded as the eighth color of the spectrum, closing the circle of saturated colors. Purple is of especial importance in the examination of the color-blind, for the reason that it forms a combination of two fundamental colors—the two extreme colors—which are never confounded with each other. In fact, from a color-blind point of view, one of two things must happen, according to the theory: either it excites but one kind of perceptive organ or it excites them all. It appears then either like a simple color, that is to say, like one of the two colors of the combination, or like white (gray). Experiment has confirmed this hypothesis. Our sample colors, therefore, are the two complementary colors of each other, *green* and *purple*. In the examination of the chromatic sense of a large number of individuals, it is, of course, of importance to decide, first, whether the chromatic sense of the individual is or is not normal. It is only after establishing the existence of a defect that its nature or degree must be determined. The sample colors are, therefore, employed with more advantage in a certain order, as the test must be accomplished as a whole, according to a plan that experience has proved the surest, most rapid, and, finally, most suitable for the purpose.

3.—THE EXAMINATION AND DIAGNOSIS.

The Berlin wool is placed in a pile on a large plane surface and in broad daylight; a skein of the test color is taken from the pile and laid aside far enough from the others not to be confounded with them during the trial; and the person examined requested to select the other skeins most resembling this in color, and place them by the side of the sample. In the first place, it is necessary that he should thoroughly understand what is required of him; that is, that he should search the pile for the skeins making an impression on his chromatic sense, independent of any name he may give the color, similar to that made by the sample. The examiner should explain that resemblance in every respect is not necessary; that there are no two specimens exactly

alike; that the only question is the resemblance of the *color;* and that consequently he must endeavor to find something similar, of the same shade, something lighter and darker of the same color, etc. If the person examined cannot succeed in understanding this by a verbal explanation, we must resort to action. We must ourselves make the trial by searching with our own hands for the skeins, thereby showing in a practical manner what is meant by a shade, and then restoring the whole to the pile except the sample skein. As it would require much time to examine each individual in this way, it is advisable, when examining a large number at the same time, to instruct all at once, and moreover to ask them to attentively observe the examination of those preceding them, so as to become more familiar themselves with the process. By this, time is saved, without loss of security; for no one with a defective chromatic sense finds the correct skeins in the pile the more easily from the fact of having a moment before seen others looking for and arranging them. He makes the same characteristic mistakes; but the normal observer, on the other hand, generally accomplishes his task much better and more quickly after having seen how it must be done, and this is the advantage of our method.

The colors mentioned in this chapter are divided into two classes:

1st. The *colors for samples* (*test colors*), that is, those presented to the persons examined; and

2d. The "*colors of confusion*," that is to say, those which the color-blind selects from the heap, because he confuses them with that of the sample.

TEST I.—The *green* sample is presented. This sample should be the palest shade (the lightest) of very pure green, which is neither a yellow-green nor a blue-green to the normal eye, but fairly intermediate between the two, or at least not verging upon yellowish green.

Rule.—The examination must continue until the one examined has placed near the sample all the other skeins of the same shade, or else, with these or separately, one or several skeins of the class corresponding to the "colors of confusion," until he has sufficiently proved by his manner of doing it that he can easily and unerringly distinguish the confused colors or until he has given proof of unmistakable difficulty in accomplishing this task.

Diagnosis.—He who places beside the sample one of the "colors of confusion," that is to say, finds that it resembles the "test color," is *color blind*. He who, without being quite guilty of this confusion, evinces a manifest disposition to do so, has a *feeble chromatic sense*.

Remark.—We must remember that we cannot allow more than five colors for "confusion." But we have here in view, not *every* kind of defective color sense, but only those important in the business of railways. The number of colors allowed is therefore sufficient, as these are the most important and most common.

TEST II.—A purple skein is presented. The color chosen must be between the deepest and lightest shades of the scale.

Rule.—The trial must be continued until the one examined has placed near the sample all or the greater part of the skeins of the same shade, or else simultaneously or separately one or several skeins of "confusion." He who selects either the light or deep shades of blue and violet (especially the deep) or the light or deep shades of one kind of green or gray inclining to blue has committed an error.

Diagnosis.—1. He who is color-blind by the first test, and who, upon the second test, selects only purple skeins, is *incompletely color-blind.*

2. He who, in the second test, selects with purple only blue and violet, or one of them, is *completely red-blind.*

3. He who, in the second test, selects with purple only green and gray, or one of them, is completely *green-blind.*

Remark.—The red-blind never ratifies the test of the green-blind, and *vice versa.* However, it happens in certain cases that the green-blind selects a violet or blue skein, but always the lightest shades. This should not affect the diagnosis. The examination may end with this test, and the diagnosis be considered as perfectly settled. It is not even necessary, practically, to decide whether the color-blindness is red or green. But to be more entirely convinced of the relation of complete color-blindness with the signal colors, and especially to convince, if necessary, the railway employés and others who are not specialists, the examination may be completed by one more trial. The one we are going to mention is not necessary to the diagnosis, and only serves to corroborate the investigation.

TEST III.—The *red* skein is presented to the subject. It is necessary to have a vivid red color like the red flag used as signals on railways.

Rule.—This test, which is applied only to those completely color-blind, should be continued until the person examined has placed beside the specimen all the skeins belonging to this shade or the greater part or else separately one or several "colors of confusion." The red-blind then chooses, besides the red, green and brown shades which, to the normal sense, seem darker than red. On the other hand, the green-blind selects opposite shades which appear lighter than red.

Remark.—Every case of complete color-blindness discovered does not always make the precise mistakes we have just mentioned in the preceding examinations. These exceptions are either instances of persons with a comparatively inferior degree of complete color-blindness, or of color-blind persons who have been exercised in the colors of signals, and who endeavor not to be discovered; they therefore usually confound at least green and brown, but even this does not always happen.

ADDITIONAL NOTE.—We have not given rules for discovering *total* color-blindness, because we have not found any cases of this kind. If any such should be found, they will be recognized, according to the theory, by a confusion of every shade having the same intensity of light. *Violet-blindness* will be recognized by a genuine confusion of purple, red, and orange in the second test. The diagnosis should be

made with discrimination. The first test often shows blue to be a "color of confusion." This may, in certain cases, be the sign of violet-blindness, but not always. We have not thought it advisable to admit defects of this kind; only the most marked cases, that other examinations establish as violet color-blindness, should be reckoned in the statistics. Finally, to acquire a desirable uniformity, it is necessary to add that in the preparatory examination, it is my habit to indicate in the journal, especially kept for that purpose, cases of *complete color-blindness* by 2 (2 R., 2 G., 2 V.), those of incomplete blindness by 1, and those of feeble chromatic sense by 0.5 (0.5 R., 0.5 G., 0.5 V.).

4.—PRACTICAL RULES AND SPECIAL DIRECTIONS FOR THE CONDUCT OF THE TRIAL.

The method, as we have said, plays an important part in an examination of this kind, not only from the principles upon which it rests, but also from the manner in which it is used. The best plan for directing how to proceed is by oral instructions and *de visu;* but here we are obliged to accomplish this by description. Now, this is always defective in some respects, especially if we wish to be brief. What has been said would evidently suffice for an intelligent and experienced physician, but it may not be superfluous to enter still further into detail to provide against any possible difficulties and loss of time. The object of the examination is to discover the nature of a person's chromatic sense. Now, as the fate of the one to be examined and that of others depend upon the correctness of the judgment pronounced by the examiner, and that this judgment should be based upon the manner in which the one examined stands the trial, it is of importance that this trial should be truly what it ought to be, a trial of the nature of the chromatic sense and nothing else, an end that will be gained if our directions are strictly followed. It is not only necessary that the examiner carefully observe them—which does not seem to us difficult—but that he also take care that the individual examined does thoroughly what is required of him. This is not always as easy as one might suppose. If it were only required to examine intelligent people, familiar with practical occupations and especially with colors, and with no other interest connected with the issue of the examination than to know whether they are color-blind or not, the examination would be uniform and mechanical. But it is required to examine people of various degrees of culture, all of whom, besides, have a personal interest in the issue of the examination. Different people act very differently during the examination for many reasons. Some submit to it without the least suspicion of their defect; others are convinced that they possess a normal sense. A few only have a consciousness or at least some suspicion of their defect. These last can often be recognized before the least examination by keeping behind the others, by attentively following the progress of the trial, but if allowed willingly remaining to the last. Some are quick; others slow. The former approach unconcernedly

and boldly; the latter with over anxiety and a certain dread. The lowest class are those who have the opposite desire, that is, to pass for color-blind, although in possession of normal sight. We will speak of these later, to enable us now to devote ourselves to those who undergo the trial in good faith, or, at least, with the desire to appear normal, even although color-blind.

In the trial it is especially desirable to confine the range of selection to the lighter shades of the test color (say green), for the trial would cause great loss of time and be less reliable if it included every shade of green. In fact, no little judgment has been exercised in the selection of the very lightest shade of the green proposed as a sample color. For it is exactly what the color-blind most readily confounds with the paler shades of gray, drab, straw, and salmon-color. If the subject were allowed to depart from the narrow limits established by the trial, it would include every shade of green, the result of which would be that he would prefer to select all the vivid shades, and thus avoid the dangerous ground where his defect would certainly be discovered. This is why it is necessary to oblige him to keep within certain limits, confining him to pure green specimens, and, for greater security, to recommend him to select especially the lightest shades. What we have just said of green applies also of course to purple.

The principle of our method is to force the one examined to reveal, himself, by an act of his own, the nature of his chromatic sense. Now, as this act must be kept within certain limits, it is evident that the examiner must direct him to a certain degree. This may present, in certain cases, some difficulty, as he will not always be guided, and does either too much or too little. In both cases, the examiner should use his influence in order to save time and gain certainty, and this is usually very easily done. This intervention is, of course, intended to put the examiner in the true path, and is accomplished in many ways according to the case in point.

We will here mention some of the expedients we have found useful:

A. *Interference during an extended selection.*—It is not always easy to confine the one examined within the limits of the method. He easily slips in the first test, for example, a yellow-green or blue-green skein among the others, and as soon as there is *one*, others follow usually, and it thus happens that, in a few moments, he has a whole handful of yellow-green, a second of blue-green, a third of both these shades at the same time. Our process has assisted us in more than one case of this kind.

(*a*) When the person examined has begun to select shades of one or several other colors than those of the sample, his ardor is arrested by taking from him the handful of skeins he has collected, and asking him whether his eye does not tell him there are one or several which do not match the others, in which case he is solicited to restore them to the pile. He then generally remarks that there is some obscuration, and proceeds in one of the following manners:

1. He rejects one after the other, the foreign shades, so that the correct remain, which is often only the sample skein. He is shown what mistake he has made. Names are used to remind him that one class of green may be yellow-green and another blue-green; and to induce him to avoid them, he is advised only to select skeins of the same shade as the specimen, although they be lighter or darker, and have neither more yellow nor blue than that. If his first error arose only from a misconception or want of practice in handling colors, he begins generally to understand what he has to do, and to do properly what is required of him.

2. Or else he selects and rejects immediately the skein of the sample itself. This proves that he sees the difference of color. He is then shown the skein as the only correct one, and asked to repeat the trial in a more correct manner. He is again put on the right track as just before, and the trial proceeds rightly, unless the error arise from a defect in the chromatic sense. Many seem, however, to experience a natural difficulty in distinguishing between yellow-green and blue-green, or the dull shades of green and blue. This difficulty is, however, more apparent than real, and is corrected usually by direct comparison. If the method requiring the name of the color to be given is used, a number of mistakes may be the result. If a skein of light green and light blue alone are presented to him, asking him to name them, he will often call blue, green, and green, blue. But if in the first case a blue skein is immediately shown him, he corrects his mistake by saying this is blue and that green. In the last case, it happens so *mutatis mutandis*. This is not the place for an explanation. It must suffice to say that the error is corrected by a direct comparison between the two colors.

There is, according to the theory, one class of the color-blind—violet-blind—who, in consequence of the nature of their chromatic sense, and, therefore, notwithstanding the comparison, cannot distinguish blue and green. But our method has nothing to do with this class of the color-blind, because such are not dangerous on railways.

(*b*) *Another process.*—If the one examined place by the side of the sample a shade, for instance, of yellow green, the examiner places near this another shade, in which there is more yellow, or even a pure yellow, remarking at the same time that if the first suit, the last must also. The other usually dissents from this. He is then shown, by selecting and classing the intermediate shades, that there is a gradation which will diverge widely if logically carried out as he has begun. The same course is followed with colors of the blue shades, if the blue-green were first selected. He sees the successive gradations, and goes through with this test perfectly if his chromatic sense is correct.

To ascertain further whether he notices these additions, or the tints of yellow and blue in the green, we can take ourselves the yellow-green and blue-green to ask him if he finds this to be so. We can judge by his answer of his sense with regard to these shades, and the object of this investigation is accomplished.

It results from all this that many who are finally considered to have a normal chromatic sense may occasionally cause embarrassments. In the main, the normal observer of this kind causes greater loss of time than the color-blind. It is astonishing to see with what rapidity the color-blind betray their defect. At least, it is found, in the majority of the cases examined by us, that the first skein of wool selected from the pile by the color-blind in the first test was one of the "colors of confusion."

B. *Intervention during a restricted choice.*—Those who evince too great slowness also require the interferences of the examiner in another manner. We can lay aside here those cases in which at the sight of the complex colors of the heap of wool, the examined finds it difficult to select a skein resembling the sample in a collection where all the particular colors seem to differ from each other, and in consequence declares immediately that he can find none resembling the specimen. It is replied that an absolute resemblance is not demanded, and that no one asks impossibilities, that time is limited, many are waiting, etc. But there are people who from natural slowness, from being unaccustomed to such business, from fear of making mistakes, and especially if previously examined and suspected of color-blindness, or from many other motives, proceed with the greatest caution; they do not even wish to touch the wool, or they search, select, and replace with the greatest care all the possible skeins without finding one corresponding with the sample, or that they wish to place beside it. Here then are two cases: on one hand, too much action with the fingers, without result; on the other, too little effort. The examiner is forced to interfere in both cases.

(*a*) At the time of a too great manual action without corresponding practical result, the examiner must be careful that the eye and hand act simultaneously for the accomplishment of the desired end.

Some people forget that the hands should be subservient to the eye in this trial, and not act independently. Thus they are often seen to fix their eyes on one side while their hands are engaged on the other. This should be corrected so as to save time and avoid further labor. When, from the manual activity of the one examined, or by the unobserved aid of the examiner, all the correct skeins or only a portion are found in the pile, it is wise to stop and invite the former to cross his hands behind his back, to step back a pace, and quietly consider all the skeins, and, as soon as his eye has met one of those for which he is looking, to extend his hand and take it. The best plan is to advise him to look first at the sample and then at the pile, and to repeat this maneuver until his eyes find what he is looking for.

This stratagem generally succeeds when nervousness from over-anxiety causes his hands to tremble. But it is not always easy to induce him to keep his hands behind his back until the moment for taking the skein in question.

(*b*) In cases of great caution, the trial is hastened, if the examiner

come to the assistance of the other by holding above the pile one skein after the other, and requesting him to say whether it resembles the color of the sample or not. It will be advisable first to select the skeins that a color-blind person would approve. If he is so, he will approve of the selection, and the question is settled. If not, he rejects them, not without a characteristic smile, or with an expression of wounded dignity. This also enlightens us as to his chromatic sense. But even the color-blind may in such a case refuse what is presented, especially if his caution is premeditated, and he suspects that a snare is intended. It is found quite frequently that he rejects the correct shades likewise presented with the others. This is not the case when one, having a normal chromatic sense, is slow and deliberative when subjected to the test under this form. He has an eye alive to the correct colors.

One process, in cases of this last kind, is to select false samples which are placed quite near the correct one, by the side, above or below, to attract the attention of the examined from the right side. It is necessary so to proceed that the true sample be displaced when the others are drawn out, so that the person examined may see it move. It does not, however, always happen to catch his eye. The best means is then to make him examine the whole, with his hands behind his back, and invite him to freely make his choice. But, whatever the process, it is necessary, in every case where one has been assisted in selecting a certain number of skeins which he has found analogous to the sample color, to make a rule not to conclude the trial without examining into the effect of the aid accorded. It is necessary to hold in the hand the approved package, and ask if he is satisfied or if he would desire any change. If he approve the choice, the diagnosis is established. The same course must be pursued with the defective chromatic sense, that the trial may be made with or without assistance. To be thorough, the name given by the color-blind to the colors in question may be likewise asked.

In cases where any one suspected of color-blindness has remained some time to see the trial of others, and where, as often happens, he has remarked the samples belonging to a required green shade, he may of course profit by it in his own trial. But this can be prevented by furtively concealing one or two of these samples. If he seem to be disposed to confound green and gray, it will be very easy to entrap him. If we do not succeed, even when assisting him, in entrapping him in this snare, the hidden samples may be put back into their places, to be convinced that the trial is correct.

From the above, it is seen that many artifices may be necessary in our examination. It may be regarded as an advantage of our method that it has at command a great variety of resources. We have by no means mentioned all; and yet many who have only read this description will probably reproach us with having devoted ourselves too much to details which seem to them puerile. But we believe that those who have examined the chromatic sense of a great number of persons, and acquired thereby considerable experience, will think differently.

5.—APPRECIATION OF THE CAPACITY OF EXAMINEES.

The method of scrutiny here described is able to detect, as we have seen, not only complete or incomplete color-blindness, but a feeble chromatic sense. Moreover, it has been proved that there is a perfect gradation from complete color-blindness on the one side to the normal chromatic perception on the other. The question then naturally arises, from our practical point of view, whether it is possible to draw a dividing line between the kinds and degrees of defective color-vision which would except those who could not cause any inconvenience to the railway service, and, in case of an affirmative answer, where such limit is to be found.

It must first be remembered that in the existing state of things, these questions neither can nor ought to be settled in the same manner in every case, since the examination is intended for individuals of two different classes: 1st, the aspirants for railway employment; and, 2d, the employés, or those already in service.

A. *Aspirants.*—We must bear in mind that in Sweden, according to the regulation in force there for the management of state railways (followed also, as far as we know, on the private lines), it is required that, in order to be admitted, each applicant "prove by a certificate from a physician that he is exempt from any kind of infirmity, disease, or defect of conformation that could be prejudicial to the exercise of his functions," and also, that among these defects of conformation, in connection with signals, are reckoned the defects of the chromatic sense, to which the managers have especially directed the attention of the physicians attached to the lines.

According to the principles we have stated, the greatest severity should be observed in this case, or, in other terms, the least defect in the sense of colors should be a sufficient ground for rejection.

B. *Persons already in service.*—We must here ask ourselves if there is no necessity to modify the limit we have just traced, in order to carry out the principle we stated before, namely, that it is necessary to adopt less severe rules to eliminate from the service those who are already employed. We here encounter great difficulties, and it will be seen that it is not possible to settle the question summarily, that is, that a well-defined limit cannot be traced. In such cases, the physician should always, when he discovers a defect in the chromatic sense, give a certificate which should indicate its nature. These indications include, as we have already said, the diagnoses: *complete red-blindness*, *complete green-blindness*, *incomplete color-blindness*, *or a feeble chromatic sense.*

We are convinced that every case of complete color-blindness of both kinds, as well as every case of incomplete of the higher degrees, should be immediately dismissed. But as regards those who may be retained, it is clear that the first question concerns those who, at the time of the trial, were regarded in the diagnosis only as having a feeble chromatic sense, and then those who in the first test merely confound gray with

the sample color. But we do not venture to lay this down as a principle, for, if it should be proved that these individuals can generally distinguish the light of colored lanterns with sufficient accuracy, this does not prove that it is so in every case, and especially not at every distance required in the service. This is why we know nothing better to advise than to refer all such cases to competent specialists, as long as the transition period of which we have spoken lasts.

In the examination of doubtful cases submitted to my judgment, I determined according to several of the methods mentioned in one of the preceding chapters. In general, these persons were all subjected to a trial according to the methods of Seebeck and of Maxwell, and an examination by means of the visual perimeter and of colored shadows, as well as the lanterns of my invention and colored glasses. These last means have capacity especially in view, and they are very suitable for the object, when it is desired to investigate those who have been already discovered, by my method of Berlin wool, as having a defective chromatic sense.

The light of colored lanterns and illuminated surfaces generally, conveniently arranged and methodically used, may serve especially in such cases to enlighten us as to the faculty of the person examined for appreciating colored signals. Our experiences of this kind have shown us that the majority of color-blind railway employés, however much practice they have had, are utterly incapable of recognizing and distinguishing the regulation colors of lanterns, especially when they are employed in the shades which are not most commonly in use in the service. This applies not only to the completely red and green blind, but also to the incompletely blind. These last require the most circumstantial investigation, and it is not to be assumed that the lower degrees can stand the trial; they may often, it is true, distinguish the signal-lights at a short distance with sufficient accuracy, but they do not succeed at a comparatively greater distance. As the places where the trials are usually made do not command such distances as railways for observing signals, signal-lights cannot of course be used for these trials. They are replaced by small illuminated surfaces, which, seen from a suitable distance, produce exactly the same effect as lanterns at a great distance. Such surfaces are made by placing a screen with a suitable opening covered with a colored glass before the flame of a lamp. This is enough to show how to dispose of the case in question.

6.—EFFORTS TO CONCEAL OR TO FEIGN COLOR-BLINDNESS.

We have announced that none of the kinds of color-blindness we have in view in this work could escape discovery by our method. But this, of course, assumes that the subject does his best in the trial and acts in good faith. If it happen that one persists either in concealing a conscious color-blindness or for some other motive, in not giving the least information by act or word it is evident that the examination must fail from this

simple reason, and that it is impossible to draw any positive conclusion with regard to his chromatic sense. The examiner may in such a case mention unconditionally in the certificate that the one examined refused to submit to the usual examination.

It is not difficult to say how it is necessary to act with regard to such persons. It should, in fact, be to the interest of each one possessing normal sight, desirous of entering the service of railways, etc., to endeavor to be competent in every respect, and consequently to give manifest proof of his sense of colors. The color-blind alone have any interest in concealing their defect; therefore he endeavors to escape the trial. Every candidate who will try to avoid the prescribed trial must therefore be considered and treated as color-blind. Such obstinacy on the part of an employé must be considered and treated as an infraction of the regulations.

But cases may arise also in which those possessing normal sight will feign color-blindness, and act as if they were so affected. This may occur when some one wishes to receive a pension before the time, or else to escape punishment consequent upon an unexpected accident. These are just the very cases that put the method and perspicacity of the examiner to the test. The examination then assumes the character of a kind of criminal inquest, where the judge and the accused must give all the attention of which they are capable to their reciprocal acts and expressions, to try to entrap each other. The one examined tries to prove that he is color-blind, while the examiner endeavors to prove that he has normal sight. The prospect of coming off victorious in so singular a contest rests, in the last resort, with him who best understands the nature of color-blindness, and has most experience in the manner in which the color-blind act. To enable the pretender to deceive the examiner, it is absolutely necessary that he surpass the latter in knowledge of color-blindness. There is in this an element of success to the examiner, as it would be extremely rare to find a railway employé or sailor who would, under the circumstances mentioned, be subjected to an examination by a person inferior to himself in knowledge. It is clear, in fact, that an examination so difficult, so minute, and involving so much responsibility, should be confided to the most competent person possible. But it is, on the other hand, very improbable that a case should occur where it would be necessary that a learned and experienced specialist would have to submit to an examination.

In the first place, examinations of this kind must rarely occur, and when they do, it must be at least in the most difficult cases, that is to say, after an accident—under circumstances where the one examined has not had much time to study his part. It will generally be seen then that he has not a profound knowledge of the nature of color-blindness, but imagines it to be a difficulty or incapacity to distinguish signal-colors or colors in general. He will, therefore, be governed by this idea, and, either he will perfectly distinguish every other color so as to mistake only the signal-colors, or else he will believe he must confound no matter what

color. But, as we have seen, each kind of color-blindness follows laws as fixed as the normal sense. Such a stratagem will not fail to violate them, and the individual will be caught in the very act.

But there is absolutely nothing which opposes the supposition that this individual may have a certain knowledge of the nature of color-blindness, or, at least, that he may have an idea of its regularity with regard to the confusion of colors. He may have studied the proofs we have cited, and, owing to the exercise and observation of the color-blind, he will know how to perform them in a manner suitable to the object in view. The examiner has always, however, the choice of other sample colors, and the Berlin wool method affords a large choice. If that does not suffice, and the individual has learned from the truly color-blind to classify the whole collection of wool according to their chromatic sense, that is to say, that he can stand the trial according to Seebeck's method, and if he is so thorough in his part that there is no means of making him depart from it by abrupt or contradictory questions, the examiner may employ for the examination a number of other known methods, but probably unknown to our individual. It must not be forgotten here that it is generally easier to discover faults committed by others than to avoid being guilty of them one's self, and one must be profoundly familiar with his borrowed part not to be guilty of inconsistencies. With regard to feigning a certain kind of color-blindness, we know by our experience with regard to this, that it is a very difficult thing, and scarcely ever succeeds before an attentive and experienced examiner. All these circumstances are advantageous for the examiner, but his superiority is not limited to this. For if it should happen—an extremely improbable thing—that a pretender were familiar with all the known tests and methods, and besides had not less practice than talent in executing them as accurately as the color-blind, the examiner has, nevertheless, the power of inventing, owing to his special knowledge, new tests, and of varying those already known.

Besides the precaution, which must not be neglected, of conducting the examination in the presence of expert and competent persons, there is an especial means, which, while being certain of preventing all fraudulent attempts, judges the accused in the usual manner, that is, by the testimony of two persons. These two witnesses should be two color-blind of the same kind as that feigned by the examined. If these two individuals are first subjected separately and independently of each other and the *pseudo*-color-blind, to the same trial as he, let the results be noted down carefully, and then the whole three together, and it will then soon be seen how the case stands with one individual. The two color-blind will in this manner give the necessary testimony without resting upon the discretion of the examiner. This manner of proceeding must, however, be employed with caution and discrimination, as the conformity between two color-blind of the same class is not absolutely perfect in every respect. The result must, therefore, always be made to harmonize by the explanation of the examiner.

COLOR BLINDNESS.*

By Joseph Henry.

[From the Princeton Review, for July, 1845.]

It is an interesting fact in reference to the dependence of one class, at least of our knowledge, on sensation, that many persons are born with defective vision and yet remain for years of their lives without being conscious of the deficiency. We know a gentleman who had probably been always near sighted, but who did not discover the peculiarity of his vision until the age of twenty-five, when it was accidentally made known by looking at a distant object through a concave lens. Many persons whose eyes are sound and capable of exercising the most delicate functions, are permanently unable to distinguish certain colors. And the number of such persons is much more considerable than we would be led to imagine from the little attention this defect of vision has excited. It is often unknown to the individual himself, and indeed only becomes revealed by comparing his powers of discriminating different colours with those of other persons. The eye also under some circumstances may lose its sensibility for particular colors, or be thrown into such an unusual state as to present all objects to the mind under the appearance of a false color. Thus if a person looks fixedly for a time at a bright red object and then turns his eye to a white wall, he will perceive a green image of the red object depicted on the white surface. A lady of our acquaintance was once thrown into an alarming but laughable paroxysm of terror by an effect of this kind. She had been for some hours attentively sewing on a bright crimson dress, when her attention was directed towards her child, who, in its sport, had thrown itself on the carpet; its face appeared of the most ghastly hue, and the affrighted mother screamed in agony, that her child was in convulsions—the other inmates of the house hastened to her assistance, but they were surprised to find the little one smiling in perfect health. The sanity of the mother became the natural object of solicitude, until the effect was properly referred to the impression made on her eye by the crimson cloth.

Phenomena of this kind are known by the name of accidental colors; they have long attracted the attention of the natural philosopher, but the explanation of them is still involved in considerable uncertainty. The hypothesis which has been most generally adopted is that the eye by long attention to a particular color, becomes fatigued with this and

* 1. Observations on colour blindness, or insensibility to the impression of certain colours. By Sir David Brewster, K. H., &c. Philosophical Magazine.

2. Memoir on Daltonism, (or colour blindness.) By M. Elie Wartmann, Professor of Natural Philosophy in the Academy of Lausanne, &c. Scientific Memoirs.

is incapable after a time, of distinctly perceiving it; while it retains its full power of perception in reference to a fresh color. The consequence of this is that when the eye is directed to a white surface, after having attentively regarded a red object, green must appear; because white may be considered as a compound of red and green, and when the perception of the red is destroyed, the green must become visible. This explanation, however well it may apply to some of the phenomena, is not sufficient for the whole. Accidental colors can be perceived in the eye itself in perfect darkness. This is shown by steadily regarding for a short time a brilliant lamp, and then covering the eyes with the hands so as to exclude all external light, a luminous spot will be perceived which passes in succession through all the colors of the rainbow.

Of the real cause of these appearances we are as yet almost entirely ignorant. Professor Plateau, of Ghent, has indeed referred them all to a few simple principles, but these appear to us rather expressions of the law of succession of the phenomena, than physical explanations of them. We do not however at this time intend to dwell on this class of phenomena, but to give a succinct account of those peculiarities of vision, in which abnormal perceptions of color are permanent, and which are fully treated of in the memoirs, the titles of which stand at the head of this article.

The peculiarity of vision called *color-blindness*, and sometimes *Daltonism*, may generally be referred to two classes. 1. Those in which all impression of color, except white and black, are wanting. 2. Those in which the individual can perceive certain simple colors, but is not able properly to distinguish between them. There are persons, strange as it may appear, in whom the sense of primary color is entirely deficient, and who, in place of red, yellow and blue, see nothing but different degrees of white and black. Professor Wartmann gives a number of cases of this kind. The most ancient of those he finds described, is that by Dr. Tuberville, in 1684, of a woman, of about 32 years of age, who came to consult the Dr. about her sight, which, though excellent in other respects, gave her no impression in reference to color, except white and black. Spurzheim mentions a family, all the members of which could only distinguish different shades of white and black. An account is given by Mr. Huddart of a shoemaker, in Cumberland, who could distinguish in different colors only a greater or less intensity of light, calling all bright tints white and all dull ones black. His peculiarity of vision was unknown to him until one day, while a boy, playing in the street, he found a stocking, and for the first time, was struck with the fact that it was called by his companions red, whereas to his mind it was capable of no farther description than that designated by the word stocking; he was thus led to conclude that there was something else besides the form and position in the leaves and fruit of a cherry tree, perceived by his playmates but not seen by himself. Two of his brothers had the same imperfection, while two other brothers, his sisters, and other relatives, had the usual condition of vision.

Of the other class, the cases are much more numerous; we shall, however, give only a few examples. Mr. Harvey, of Plymouth, mentions a

tailor who could see in the rainbow but two tints, namely, yellow and bright blue. Black appeared to him in general, green, sometimes crimson—light blue appeared like dark blue, crimson, or black—green was confounded with black and brown—carmine, red, lake, and crimson with blue.

But the most interesting case of this kind, is that of the celebrated chemical philosopher, Dr. Dalton, of England. He published an account of his own case and that of several others, in the Transactions of the Manchester Society, in 1794. Of the seven colors of the rainbow, he could distinguish but two, yellow and blue; or at most, three, yellow, blue, and purple. He saw no difference between red and green; so that he thought the color of a laurel leaf the same as that of a stick of red sealing-wax. A story is told of his having, on one occasion, appeared at the quaker meeting, of which he was a member, in the usual drab coat and small-clothes of the sect, with a pair of flaming red-colored stockings to match. Whatever may be the truth in reference to this story, we have the assertion of Professor Whewell, that when Dr. Dalton was asked with what he would compare the scarlet gown with which he had been invested by the university, he pointed to the trees, and declared that he perceived no difference between the color of his robe and that of their foliage. Dr. Dalton found nearly twenty persons possessed of the same peculiarity of vision as himself; and among the number, the celebrated metaphysician, Dugald Stewart, who could not distinguish a crimson fruit, like the Siberian crab, from the leaves of the tree on which it grew, otherwise than by the difference in its form.

On account of the prominence which Mr. Dalton's publication gave this defect of vision, the continental philosophers gave it the name of *Daltonism*. To this name, however, several British writers have strongly objected. If this system of names were once allowed, say they, there is no telling where it would stop, the names of celebrated men would be connected, not with their superior gifts or achievements, but with the personal defects which distinguish them from their more favoured but less meritorious cotemporaries. Professor Whewell proposed the term *Idiopts*, signifying peculiarity of vision; but to this name Sir David Brewster properly objected, that the important consonant *p* would be very apt to be omitted in ordinary pronunciation, and so the last state of the Idiopt would be worse than the first. The name *color-blindness*, suggested by Sir David, although not in all cases free from objection, is perhaps better than any we have seen proposed.

It has already been stated that the number of persons affected with color-blindness, is much more considerable than is generally imagined They are often themselves ignorant of their imperfection of vision, particularly when it is restricted to the want of power to discriminate between colors nearly related to each other. Professor Seebeck found five cases among the forty boys who composed the two upper classes of a gymnasium of Berlin. Professor Prevost, of Geneva, stated that they amounted to one in twenty; and Professor Wartmann does not think this estimate much exaggerated.

Observations on this peculiarity of vision have as yet been confined,

so far as we know, to Europe, with the exception of two cases described by Dr. Hays, of Philadelphia, in the Proceedings of the American Philosophical Society. It has also as yet been found only among the white race, although sufficient observations have not been made to render it probable that it is confined to this variety of the human family. The question has been asked, whether there is any external sign by which to detect, with simple inspection of the visual organ, a case of color-blindness. Professor Wartmann remarks, that he would not venture to give an answer to this question in all cases in the negative. I have observed, says he, in the case of *Daltonians* whose eyes are brown, of the color which the English call hazel, a golden lustre of a peculiar tint, when the eye was viewed under an incidence of some obliquity.

Color-blindness is found much more common among men than women. Out of one hundred and fifty registered cases, there are but six of females, and one of these is doubtful. It has been conjectured that needle-work on a variety of colored articles, might be the means of counteracting the tendency to this defect, as well as to produce a delicacy of discrimination of different shades of color not possessed by those otherwise employed. But, in answer to this, it has been remarked, that in the case of Daltonians engaged in painting, there has been found but little, if any improvement of condition of the vision; and the very employment of the females on works which require a constant comparison of color, would daily reveal cases of blindness of this kind, did it frequently exist in the female sex. This peculiarity of vision is principally congenital. Professor W. has found but two exceptions. In one of these, colors were perceived in the usual manner, until at the ninth year, when at that time the boy received a violent blow on the head, which fractured the skull, and rendered surgical operations necessary. The fact, however, that three of the brothers of this individual were affected with the same kind of vision, renders it probable that he was constitutionally predisposed to this peculiarity.

With regard to hereditary predisposition there are some persons in whom this defect of vision occurs, whose relatives have never been known to be affected with it; others appear to have inherited it from their fathers through several generations, both on the maternal and paternal side. The boy before mentioned, as becoming blind at the age of nine years, was the eldest of eleven children, seven males and four females; these were singularly divided into two sets, one of which consisted of individuals with blond hair, and all the males with defective vision; the other, of those with red hair and ordinary power of vision.

Dr. Seebeck, as well as Professor Wartmann, has made a series of experiments to determine whether a person of this peculiarity of vision possesses the power of perceiving differences in colors which appear identical to us. The result of the investigations of both these philosophers was that he does not. Another problem has also been solved by the last-mentioned gentleman, in reference to the difference between a person with this defective vision, and one of ordinary conditioned sight, in

the perception of complementary colors. He found that colors which we regard as complementary, or such as when mingled together produce white, do not appear as such to those affected with abnormal vision. They are not however insensible to accidental colors, but the feeling which results from the fatigue of attempting to produce these appears to be more painful in them than in us.

Various hypotheses have been advanced by different persons for the explanation of color-blindness. Mr. Dalton supposed that his peculiarity of vision, as well as that of those whom he had examined, depended on the fact that the vitreous or principal humour of the eye, in these cases, instead of being colorless and transparent was tinged with a blue. After his death, in obedience to his own instruction, his eyes were examined by his medical attendant, Mr. Ransome, but the vitreous humour was not found to exhibit any tinge of blue; on the contrary, it was of a pale yellow color. Objects viewed through it were not changed in color as they should have been had the hypothesis been true. Indeed, were the supposition correct, the same effect should be produced by blue spectacles, which is known not to be the case.

Stewart, Herschel and others are of the opinion that this malady of vision is attributable to a defect in the *sensorium* itself, which renders it incapable of appreciating the differences between the rays on which the sensation of color depends. Sir David Brewster conceives that the eye, in the case of color-blindness, is insensible to the colors at one end of the spectrum, just as the ear of certain persons is insensible to sounds at one extremity of the scale of musical notes, while it is perfectly sensible to all other sounds. He knows nothing about the *sensorium* or its connection with, or mode of operation upon, the nerves of sensation; and from the analogy of sight and hearing, he has no hesitation in predicting that there may be found persons whose color-blindness is confined to one eye, or at least is greater in one eye than in the other. Nor is this, says he, wholly a conjecture from analogy, for my own right eye, though not a better one than the left, which has no defect whatever, is more sensible to red light than the left eye. The case is precisely analogous with respect to his ears, for certain sounds; and no person, it is presumed, will maintain that there is a sensorium for each ear and each eye.

Whatever may be the cause of the inferiority, there exists a very easy means of rectifying it to a certain extent. This method, first used by Dr. Seebeck, consists in viewing colored objects through colored media. Suppose the medium to be a piece of red glass; the impression of a red body and of a green one on the eye of a person like Dr. Dalton, would be different, although with the naked eye they would be the same. The red glass would intercept much more of the light of the green object than of the red one, and hence the two would be readily distinguishable by a difference in the intensity of the illumination of the two objects. Nothing can equal the surprise, says Professor Wartmann, of a *Daltonian* when the errors which he commits every day in the appreciation of colors are thus disclosed to him.